WASTEWATER TREATMENT BY INTERACTION WITH SOIL SYSTEMS

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CERTIFICATE

Certified that the work presented in this thesis entitled 'Wastewater Treatment by Interaction with Soil Systems' by Shri Vinod Tare has been carried out under my supervision and it has not been submitted elsewhere for a degree.

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A study of the literature revealed that studies on wastewater treatment by soils with primary objective to consider 'Soil System' as a wastewater treatment means are very few. The objective of this investigation was, therefore to develope a suitable soil system and to study the parameters such as hydraulic loading pattern, acceptance rate etc. from the point of view of purification of the wastewater.

Sand (Effective Size = 180 μm; Uniformity Coefficient=2.11) and Kanpur silt (Effective size = $<$ 1 μm ; Uniformity Coefficient = $>$ 20) were mixed in different proportions as an initial step towards the development of suitable soil system. From wastewater acceptance and treatment point of view, sixty percent sand and forty percent silt was found to be the optimum soil system as a result of com-

promise between wastewater acceptance rate and its purification.

From the study on effect of the hydraulic loading pattern on the above soil system, it was found that hydraulic failure occurred in 37 days after continuous flooding of wastewater at 0.24 cu.m./sq.m./day (5 gpd/sq.ft. applied five times a day) of loading rate. Further from the observation of percolation rates, it was concluded that with lower rate of loading (0.096 cu.m./sq.m./day applied twice a day and 0.144 cu.m./sq.m./day applied thrice a day) hydraulic failure can be postponed for a significant period of continuous flooding which in turn reflects the importance of wastewater application techniques.

Initial chemical treatment (alum coagulation), given to wastewater to reduce organic and TSS loading, maintaining the same hydraulic loading, was very effective in enhancing the treatment and service time. Hydraulic failure did not occur even after 90 days of continuous flooding at 0.24 cu.m./sq.m./day of loading rate when wastewater was given alum treatment as against 37 days mentioned earlier. The increase in service time thus achieved amounts to about more than three times.

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1. INTRODUCTION

The soil is one of the three great natural reservoirs where dangerous pollutants can accumulate. It has a great capacity for receiving and decomposing wastes and pollutants of many kinds.

Application of waste-water to the soil as an alternative to more conventional methods of wastewater management has become a controversial topic. Some staunch proponents (Merz, 1956; Devries, 1972; Michel, et.al., 1974; and Robert, et.al., 1975) of land based alternatives foster the impression that crop irrigation method for applying wastewater to the soil is a ready solution to the multitude of wastewater management problems. Conversly an equally adamant group (Walton, 1960; and Carlson, et.al., 1975) oppose the idea of land disposal of wastewater and therefore uptill now the technical facts supporting the method of land disposal have been ignored or glossed over.

Land disposal, the practice of disposing of domestic and/or industrial wastewaters in the earth's soil mantle, instead of in its surface waters has received a great deal of publicity over the past few years, and has acquired many influential advocates who have promoted the age old method to the point where it could become the only method

of wastewater disposal legally permitted any where (Egeland, 1973). This shifting of thinking from water disposal to the land disposal has occurred despite the fact that many wastewater disposal professionals (Carlson, et.al., 1975) have advised that land disposal is a very costly strategy and have warned that the extensive use of land disposal system will result in the devastation of vast areas of land, serious contamination of air, accelerated depletion of power resources, and ultimetely, more severe water pollution than that which exists today.

As with natural waters, distinctive regimes of aerobiosis and anaerobiosis in soil must be distinguished when wastewater is disposed on land. Well drained aerated soils under favourable circumstances could have a natural oxygen supply upto or even exceeding 10 times the daily rate available to an equivalent volume or area of water, but water logged soils far less (Imhoff, et.al., 1971). Moreover, once water has percolated deeper underground, the rate of oxygen supply to it becomes negligible. Hence unless it has been relatively highly purified beforehand, opportunities for purification are confined to mechanical filtration, which in many cases would not be sufficient, and residual pollution may be present practically permanently wherever such water may travel. Land disposal system should be operated so as to

ensure always an overall positive balance of oxygen supply over demand.

Domestic wastewater is a significant source of water pollution. Primary and secondary treatment donot prevent nutrient enrichment of receiving waters, because they remove only a fraction of the carbon and soluble components such as nitrogen and phosphorous. A wastewater effluent renovation system consisting of a combination of conventional secondary treatment and recycling of the effluent by applying it to forested and cultivated areas has been in operation since 1962 (Parizek, et.al., 1967). As the effluent percolates through the soil, it is renovated as a result of the soil acting as a 'living filter', where as the ground water reservoir is recharged with high quality water, the 'living filter' method is in fact a biological form of tertiary treatment. The idea underlying this approach is that effluent can be an asset to society rather than a nuisance, it is mostly water that contains essential plant elements such as nitrogen and phosphorous, and plants requires both water and nutrient in large quantities. Indeed, in water short areas a large volume of water is used in irrigation and the soil fertility is augmented by the addition of nitrogen, phosphorous and potassium in the form of chemical fertilizer. By changing the path way of wastewater effluent

from city to receiving water to city to land, both water and plant nutrients are returned to the cycle of soil-plants-animal and/or man while at the same time preventing or minimizing nutrient enrichment of receiving waters.

Though it is recognized that soil has been used as a waste disposal and water reclamation resource for many years, the intense interest in air and water pollution has over shadowed the role that the soil environment plays in the overall environmental quality picture.

The apparent neglect is principally because past disposal of wastewater to soil usually has been highly effective. However, recent urbanization and industrialization have concentrated soil disposal areas and created volumes and types of wastewater which no longer are assimilated readily (Meyer, 1953). In addition ground and surface water pollution from soil disposal sources has become increasingly evident.

As with water courses, soil has a definite assimilative capacity that can be exceeded. Thus, information regarding the limitations and benefits of utilizing the assimilative capacity of soil is needed.

However, the amount of land that may be available for wastewater recycling is often limited

particularly in the vicinity of large population centres, and in certain cases it may be necessary to subject land areas to condition of heavy loading. Accordingly more information is needed about the behaviour of soils under these conditions.

Though there is sufficient literature available on the effectiveness of wastewater purification by soils, available laboratory as well as field data suggests that several factors, such as grain size distribution and composition, water and organic molecule retention, sorptive capacity of soil and nature of feed, all have significant influence on achieving quick and lasting treatment, but very few studies were undertaken in this respect. The present effort has, therefore, been devoted to studying the influence of soil particle size, permeability, adsorptive capacity, organic and hydraulic loading, nature of feed suspension, application technique, and the capacity to regenerate naturally on drying.

2. LITERATURE REVIEW

2.1 Historical Note:

Wastewater disposal to soils is almost as old as the history of mankind, and is a practice so natural and logical that its origins are lost in antiquity. Evidence of it abounds in early writings and in the remains of long-forgotten structures. For example, a Mosaic Law recorded in Deuteronomy required that human wastes be burried outside the camp area; and archaeologists note that 6000 years ago the Sumerian citizens discharged their wastes into a pit, often 40 to 50 feet deep, which had been excavated in the sands lined with punctured ceramic tiles, and partially filled with potsherds. Essentially unmodified, this system has endured to the present day in the land of the ancient Sumerians. In Europe it appeared in a modified form as the cesspool, and later, in America, as the pit privy and, currently, as the septic-tank seepage pit, ground water recharge basins and as a means of wastewater treatment.

2.2 Wastewater Treatment by Soils: a Realistic View:

As land application of wastewater grows in future years, the question of consequences must be raised; there are many benefits, but some unknowns remain (Michel, et.al., 1974).

By the land application of wastewater is meant of course, that the wastewater is applied to the land, not delivered directly to receiving waters. Implicit in the concept is the expectation that it would offer two sets of benefits. First, the soil and ground cover will provide treatment, ultimately returning good quality water to the system. Next, the wastewater can be used as an irrigant for water-poor soils, yielding crops and other benefits. To get a realistic view of the wastewater treatment by soils, following points need be considered.

1. Treatment efficiency of natural soils:

In general, natural soils are efficient purifying media (Robeck, et.al., 1963; Devries, 1970; Bouwer, 1970; and Young, et.al., 1975). The system acts as a complex, mixed media filter with particle size ranging from over 500 microns to less than one micron. Suspended matter is filtered out by the soil particles and its organic matter is decomposed by the biologic community living in the soil. Nutrients are utilized by the plants, or precipitated out by the soil. The unused water, after passing through the soil filter, can be collected by drainage system or natural aquifers, where it again becomes available for use.

In water treatment, the three quantities of major interest are treatment capacity or rates, removal efficiency with respect to various impurities, and amount of water recovered. For land application, all of these parameters are functions of the characteristics of the soil, the influent to soil, and the vegetative cover (Robeck, et.al., 1964; Hajek, 1969;and Schwartz, et.al., 1970).

Like any treatment substance, the soil must be properly managed to maintain its efficiency. It exhibits the same properties as the filtration, adsorption and ion exchange systems that are standard processes in water and wastewater treatment, and experience with these processes demonstrates that a system can not be used indefinitely without regeneration and replenishment (Allison, 1947; Devries, 1972; Rice, 1974; and Jubboori, 1974). Thus, the infiltration capacity of the soil diminishes if it is inundated continously with wastewater containing high organic loading; and its ion exchange and adsorptive capacity decreases(Lance, et.al., 1972; Sawhney, et.al., 1975; and Lance, 1977). Fortunately, intermittent resting restors the soil to its original capacity (Lance, et.al., 1972; Bouma, 1973).

2. Benefits:

The value of crops grown with wastewater application are an important benefits of the land treatment

method.

Controlled use of wastewater on land can provide ecological and recreational benefits which are substantial (Merz, 1956; and Gordon, et.al., 1975). Ecological and recreational benefits are difficult to quantify, since they include aesthetic and emotive values.

3. Unknowns:

In the application of wastewater to soil, a crucial factor is whether there will be a long term reduction in the productive capacity of the land. Clearly, detrimental effects to the soil, if permanent and severe, would be a strong deterrent against implimenting the concept, regardless of its advantages in other areas.

In this context, the major problem is also the major unknowns, and that is the existence of minute amounts of heavy metals (copper, cadmium, zinc, lead etc.) in the effluent (Day, et.al., 1972). The problem is that they will tend to accumulate in the soil, building up over a period of time into quantities that are not 'natural' constituents of the soil. The unknown is that what effect they will have.

Some evidence (Michel, et.al., 1974) does exist however, that the heavy metal accumulation over long periods

does not reach toxic levels.

4. Environmental impact:

The significant conclusion from the studies of Michel, et.al., (1974) is that, though negative impact occurs, but is not general. Further such impacts can be mitigated or controlled largely, by variations of four measures. These are: exclusion of certain specific area from wastewater application, pretreatment of the recovered wastewater; and monitoring and control of the wastewater application rates and periods.

On the other hand, the wastewater application was found to have strong positive impacts (Michel, et.al., 1974). These include: increase in the diminishing marsh lands and wet lands; prevention of salt intrusion in surface and subsurface waters; establishment of pretreatment flows in intermittent streams; increase in desirable vegetation (aside from crops); enhancement of fisheries and increase in wild life populations; and others.

5. Cost:

The cost of implementing a wastewater application system depends on the size and the extent of the system, and on the nature of application process. This process consists of three parts: conveyance of the wastewater to the site,

storage, treatment and application methods at the site, and recovery of water.

The choice of the system depends largely on topography, soils and subsoil conditions, vegetable cover, ground water levels and water quality protection requirements (Michel, et.al., 1974).

Design factors include flow requirements, the need to locate storage facilities, protection and utilization of natural drainage patterns and provision for surface irrigation as permitted by slope and soil characteristics (Robeck, et.al., 1964; and Thomas, et.al., 1969).

6. Evaluation of soil system for wastewater treatment:

The evaluation of the wastewater application concept must be based not on how closely it approaches the ideal, but on how it compares with alternative concepts (Michel, et.al., 1974).

There are basically two such alternatives: continue discharging the effluent in receiving waters, or construct treatment plants. The first alternative though least expensive, is environmentally least tolerable by present day standards. Existing problems and potential damages have been well documented (Dennis, 1959).

The second alternative though poses few environmental unknowns, none of a potentially prohibitive nature, but is costly and difficult to achieve (Michel, et.al., 1974).

The difference in implementation costs for either of the two remaining alternative are not great for equal levels of treatment. The land application concept appears to be atleast competitive on a cost basis, without taking into account all potential benefits (Bouma, et.al., 1973; Carlson, et.al., 1975; and Robert, et.al., 1975).

2.3 Factors Affecting Adoption of Wastewater Treatment by Soils:

There is an increasing need to conserve water resources throughout the world (Day, et.al., 1972). Because water can not be manufactured, it is necessary to control its use and reuse. To reuse the water increased level of treatment for municipal wastewaters will be required. The 1972 water pollution control Act in U.S.A. amendments established the goal to prevent, reduce and finally eliminate water pollution by 1985 (Scranton, Gillette, Inc., 1973). Cities and towns are examining alternative treatment techniques to meet the higher treatment standards (Carlson, et.al., 1975).

One such technique is land treatment: the controlled application of wastes on land to purify the wastes and aid crop production (Merz, 1956). This is a long established technology in arid regions (Stone, 1953). Municipal waste treatment officials emphasize the collecting and treating of a given volume of wastes to a given level of treatment at the lowest possible operating and local construction cost (Robert, et.al., 1973).

Land treatment sites for municipal effluents range from agricultural crops to golf courses. The need to purchase land near a town is often given as an obstacle to low cost land treatment.

The decision to select land treatment rather than inplant treatment is a long run decision. Future, prices of by-products, required degree of treatment over the life of the facilities and growth in volume of wastes must be considered (Carlson, et.al., 1975). The analysis by Carlson, et.al., (1975) has shown that municipal sanitation officials have responded to economic incentives in selecting treatments technology to obtain cleaner streams. Required higher degree of treatment can cause adoption of land treatment especially in areas where stream flows and rain-fall are small.

The analysis of Carlson, et.al., (1975) strongly indicates that municipal officials should try to determine what degree of treatment will be required in future.

Many of the factors influencing soil system performance in treating liquid wastes are immutable facets of the environment. These factors frequently represent obstacles to be overcome in the design of a soil system (Schwartz, et.al., 1970). The potential of a soil site for waste treatment may be determined in part by soil's physical and chemical characteristics, which may vary from site to site, making the formulation of any general conclusion difficult (Robeck, et.al., 1964; and Hajek, 1969). The only important physical characteristic of a soil site is the unsaturated depth of soil. Greater depth serves to increase the adsorptive capacity of the soil system by brining the infiltrating water into contact with a greater mass of soil, but also affects hydraulics and therefore biological treatment as well (Schwartz, et.al., 1970).

One major factor affecting the adoption of wastewater treatment by soils is climate (Merz, 1956). Climatic effects are many and varied (Schwartz, et.al., 1970). This affects not only the microbial metabolic rate and the rate of chemical reaction (Thomas, et.al., 1969), but also systems of

hydraulic through freezing, drying and cracking of soil (Schwartz, et.al., 1970)

2.4 Soil Clogging

Although the percolation test may be said in considerable truth to measure the rate at which water moves through a soil, and thus be used to identify soils which might or might not be suitable for percolation systems, the conditions which govern the entrance of water into the soil surface are the controlling factors in percolation system design (McGauhey, et.al., 1963). To isolate and evaluate such factors it is necessary to explore the phenomena which lead to clogging of soils.

In the absence of specific knowledge of the nature of clogging, percolation field design has to an important degree been based on a simple hydraulic concept in which soil behaves as a rigid matrix through which water flows at rates proportional to pressure, percentage and size of pores and the tortuousness of the path it is compelled to follow. It is assumed, tacitly, that small particles will pass on through the matrix, whereas large particles, removed by mechanical screening will 'blind', or clog, its surface. Thus, once precaution has been taken to keep relatively large particles out of the influent to the soil the rate of infiltration becomes identical with the rate at

which the soil will transport water by percolation, which in turn is a function of the characteristics of the soil (McGauhey, et.al., 1963).

2.4.1 Nature of Clogging

The factors contributing to soil clogging are usually classified as chemical, physical, and biological (McGauhey, et.al. 1963). But strictly speaking, clogging is a physical phenomenon resulting from the interaction or the integral of all three (Rice, 1964). Increased physical resistance to flow results from changed friction or viscosity coefficient or from reduction in size and volume of pore spaces. The practical consequences in the case of percolation system derive from these and a number of other relationships. The biochemistry of aerobic versus anaerobic systems, hydraulic loading,organic loading, system geometry, and various operational procedures are among the most important aspects involved (Jones, 1965; Lance, et.al., 1972; and Devries, 1972).

2.4.2 Chemical Factors in Soil Clogging:

Of the chemical factors responsible for changing the physical nature of soil, none is more important than ion exchange. Best known is the deflocculation of soils, resulting in decreased permeability, when sodium represents

a high percentage of the cationic content of water. Of course, not all soils are deflocculated to the same extent but, unfortunately, those containing clay, and hence least suitable for percolation system, are the ones most affected (Fireman, et.al.,1945).

2.4.3 Physical Factors in Soil Clogging:

Most information on the physical behaviour of soils which results in clogging derives from research on the irrigation of agricultural soils, and from studies of ground water recharge by surface spreading of flood water or sewage effluents. Huberty (1944) found that soils with wide ranges of particle sizes are compacted during agricultural operations to a much higher degree than are soils with a more uniform size. Kozlova (1933) demonstrated experimentally that small particles perched on larger particles are free to move with water through relatively large interstices. A rapid reduction in water intake by bare soils due to this and other phenomena was observed by Duley (1939).

An important physical factor in soil clogging and one that is discussed in connection with operational procedures and the maintenance of aerobic conditions, is the retention of soil moisture by capillarity. Experiments with soil columns in ditergent studies by Klein, et.al. (1963)

showed that for each soil of small enough grain size to make surface tension and capillarity major forces, there is a minimum length of soil column necessary to produce draining once application of liquid is stopped. At lesser column length, which in a practical case might result from a perched aquifer or a normal ground water surface too close to the infiltration surface, water is essentially suspended in the soil by capillarity. This excludes oxygen from the apparently unloaded field and so maintains anaerobic conditions, with the drastic clogging result described in the following section.

2.4.4 Biological Factors in Soil Clogging:

The effects of organic matter on the clogging of soils are both physical and biochemical. For the sake of convenience they are here considered as biological phenomena.

Allison (1947) demonstrated that the longterm decline in percolation rates is the result of microbial activity. To support microbial activity there must, of course, be organic matter present in the soil or in the percolating water.

Surface clogging in the presence of organic matter involves several phenomena:

(1) Reduction of pore space by deposited suspensed solids.

(2) Reopening of pore space by bacterial decomposition of entrapped organic solids.

(3) Reduction of pore space by bacteria growing on entrapped or on dissolved solids.

(4) Reopening of pore space by decline of bacterial growth during drying or periods of inadequate substrate.

These phenomena likewise support a conclusion that contnuous inundation of a soil is to be avoided if biological clogging is to be minimized.

2.4.5 Clogging by Ferrous Sulfide:

Experiments of Laak (1970) with soil clogging under anaerobic conditions led to the discovery of ferrous sulfide as an important clogging agent in anaerobic percolation systems. The back layer of soil at the surface of many soils receiving sewage effluent had been interpreted as indicative of the depth to which organic matter had penetrated. Investigations, however, demonstrated this to be ferrous sulfide.

2.5 Effect of Pretreatment to Wastewater:

Increased pretreatment of domestic wastewater before its application to the soil surface resulted in the reduction of the clogging rate of the soil surface (Laak, 1970). It has been shown (Weibel, et. al., 1959) that reduced concentrations of TSS resulted in less soil clogging and that increased substrate concentration with constant TSS increased soil clogging. In another study (Winneberger, et. al., 1960) it was shown that aerobic pretreatment, in comparison with anaerobic pretreatment, did not sufficiently change the clogging rates of soils when the sum concentration of TSS and BOD in the influent to soil system remained same.

The developments of improved design criteria for seepage beds (Coulter, et. al., 1961) introduced a loading factor that took into account the importance of the amount of treatment given to the wastewater before the liquid comes into contact with the soil. During the study of Winneperger, et. al., (1960) it was found that soil columns loaded with septic tank effluent and extended aeration plant clogged at different rates.

Laak (1970) suggested that for design purposes, if the BOD plus TSS load is decreased by 50 percent by

aerobic treatment, the hydraulic load or unit load could be increased by approximately 25 to 40 percent for the same service time. Further he (Laak, 1970) recommends that these general approximations could be useful for selecting degree of pretreatment and soil application areas for various wastewater treatment and disposal methods. Laak (1970) concludes that soil clogging failure loads should also be expressed in terms of TSS and BOD of the liquid. It seems that the service time of the soil surface is directly related to the sum of total suspended solids and the BOD (Laak, 1970).

Thomas, et.al., (1969) found that in silica sand the different rates of degradation observed for the organics from septic tank effluent (78 percent) and from the secondary effluent (68 percent), as a result of pretreatment processes. The septic tank effluent had undergone anaerobic stabilization and contained organics which are oxidizable readily in the aerobic environment maintained in the soil. The secondary effluent already had received some stabilization by aerobic organisms, and its further oxidation in the aerobic soil environment might be difficult (Thomas, et.al., 1969).

2.6 De-Contamination of Wastewater Through Soils

Decontamination of wastewater by soils is studied very extensively by many workers, working in this area with various soil types and conditions in laboratory and fields. Their findings are reported here in following sections with each type of contaminant separately.

2.6.1 C.O.D. and B.O.D.:

The results from the soil lysimeter studies with septic tank effluent by Robeck, et.al., (1964) indicate that soil system can be made to degrade synthetic organics as well as the usual COD components. Thomas, et.al., (1969) found the C.O.D. removal by silica sand from septic tank effluent to be 78 percent and that from secondary effluent to be 68 percent. From the studies of Schwartz, et.al., (1970) it appears that there is some minimum depth beyond which little additional treatment is noticable. They found that the minimum depth for COD removal is 0.6 m (2 ft.). The COD reduction occured at this depth in their study was about 74 percent. Devries (1972) reports that the removal of BOD was close to 100 percent by sand filters when waste-water effluent from primary treatment plant was applied for 240 days at a rate of 20 cm/day, 5 days/week with a daily application period of 2 hrs.

2.6.2 Phosphates:

The data by Day, et.al.(1972) indicate that there is a considerable increase in phosphate levels in soils, when the same is irrigated with wastewater effluent in both Ap and C-horizon which in turn indicate the phosphates removal from wastewater effluents. About 100 percent phosphate removal was obtained in the study of Devries (1972) from primary treatment plant effluent with fine sand filter. He (Devries, 1972) postulates the cause of phosphates removal to be the coatings of Fe_2O_3 and Al_2O_3 on sand grains. Lance (1977) reported that orthophosphate - phosphorous in water from a well in the centre of the field recharge system ranged from 30 to 70 percent of the total phosphate concentration in the secondary effluent over a 4 year period. It was suggested that variation in phosphates removal might be due to differences in application rate and phosphate concentrations. Recent investigators (Magdoff, et.al., 1974; Sawhney, et.al., 1975) showed that phosphates applied to soils in fertilizer or wastewater moves only slowly through the soil profile. Adriano, et.al., (1975) observed that subsurface waters from two sandy soils that had been irrigated with wastewater at 5-15 cm/day for 10-20 years contained as much as 0.6×10^{-4} M-P.

Sawhney (1977) showed that phosphate in wastewater percolating through soil column is readily sorbed by the soil. However, after the breakthrough, increasingly larger concentrations of phosphates appear in the effluent. Consequently, after, prolonged use of a soil of low sorption capacity and in cases of high and perched water tables, sub-surface waters may contain undersirably larger concentration of phosphates. Almost similar results are reported by Magdoff, et.al., (1974) from column studies on mound type of disposal system for septic tank effluent.

2.6.3 Nitrogen :

Day, et.al., (1972) in their study on 'Effect of Treatment Plant Effluent on Soil Properties' found that nitrates accumulated to a level of 132 mg/lit. in Ap horizon and 38 mg/lit. in C-horizon when the soil is irrigated with wastewater treatment plant effluent as against 65 mg/lit. in Ap horizon and 12 mg/lit. in C-horizon when the same soil was irrigated with well water. This according to them (Day, et.al., 1972) was due to the conversion of ammonia and organic nitrogen to nitrates by microbial degradation in the soil environment. Studies by Young, et.al., (1975) to determine whether nitrification may be accomplished in PBR units at wastewater temperatures below 10°C, indicated that nitrification does occur , but to a very low extent.

Schawartz, et.al., (1970) reported the minimum depth of unsaturated zone for ammonia-nitrogen removal to be 1.2 m (4 ft.). The removal was about 82 percent at this depth.

Lance, et.al., (1972) concluded that nitrogen was not removed from secondary sewage effluents when soil columns were flooded on short frequent cycles, but almost all of the ammonia and organic N was transformed to the nitrate form. However, longer flooding periods consistently produced a net N removal of 30 percent. Further, when same workers (Lance, et.al., 1972) compared column and field data, commented that columns were good model of the field system. Significant reduction in N concentrations were also observed by Magdoff, et.al., (1974) in their studies on columns, representing mound type of disposal system.

2.6.4 ABS :

Walton (1960) states that, 'The many cases of ground water pollution involving ABS traceable to waste discharge to the soil indicate that this method of treating sewage also is not always effective in removing or degrading ABS'. Robeck, et.al., (1962) showed that there was not appreciable breakdown of ABS in water saturated soils. Further Robeck, et.al., (1963) made following conclusions from their work:

1. ABS in the effluent from a septic tank can be degraded from a level of 5 mg/lit. to 35 mg/lit. to less than 0.5 mg/lit., if applied properly to certain unsaturated soils.

2. The usual organisms found in sewage and soil were able to degrade ABS if sufficient time was provided for them to adjust and handle new organics in the waste.

3. Coliform organisms, odour, turbidity, and COD were usually greatly reduced and nitrification took place when the ABS degraded below 0.5 mg/lit.

2.6.5 Microorganisms:

The results from soil lysimeter studies (Robeck, et.al., 1964) with septic tank effluent indicate that coliform organisms can also be removed in the presence of modern contaminants like synthetic organics. They further stated that slow flow rates promotes the reduction of pathogenic organisms. Magdoff, et.al., (1974) from their column studies on mound type of disposal system reported that total bacteria counts in column effluents were one to two orders of magnitude less than influent values. The total coliform (TC) counts in column effluents were also lowered as compared to the influent. The same workers (Magdoff, et.al., 1974) also

found that fecal streptococci (FS) and fecal coliform (FC) were not detected in column effluents even though the average numbers of these organisms in the influent were 3.8×10^4 and 1.7×10^6/100 ml. respectively.

2.6.6 Viruses:

Following a review of the literature in this area, Gerba, et.al., (1975) concluded that the removal of viruses by soils is principally due to adsorption. Salt concentration, pH, presence of organic matter, soil composition and flow rates may all affect the degree of retention of viruses by soil particles. Generally, greater virus removals are accomplished at lower flow rates, pH levels and concentrations of soluble organics, while low levels of cations and clay tend to decrease virus removal.

Regarding the laboratory studies of virus movement through soil, Drewry and Eliassen (1968) showed that nine different soils from California and Arkanas were capable of removing over 99 percent of the viruses (T_1, T_2 and F_2 bacteriophages). Later, Drewry (1969) observed 99 percent virus adsorption on three of the four soils studied using F_2 bacteriophages. Young and Burbank (1973) observed that only 35 percent of virus was removed or retained by 15 inch column of Tantatus soil which was characterised by

rapid drainage. They also observed that even 6 inch columns were unable to effect 100 percent retention of poliovirus with initial feed concentration of 1.5×10^6 PFU/ml in a 2.5 inch soil column. Koya and Chaudhuri (1977) found that three Indian soils, viz., Lateritic soil, Black cotton soil and Kanpur silt were effective in removing viruses from water in terms of both batch sorption tests as well as the column studies. Virus particles retained in the soil were not inactivated and virus retention was dependent on the type and amount of the clay content as well as the chemistry of the system.

Major field tests concerning the movement of viruses in ground water were conducted by Merrell and Ward (1968) at the Santee Water Reclamation Project at Santee, California. They concluded that the virus was removed in less than 200 ft. of travel. Recently, Wellings, et.al., (1974) isolated viruses in wells 10 ft. and 20 ft. below the soil surface in a wastewater reclamation pilot project near St. Petersburg, Florida. No virus was detected in these wells for the first 5 months of the study. Hence, the retention of viruses by soil particles does not result in their permanent immobilization from the liquid phase, and changes in water quality can result in their deadsorption and further subsurface travel.

2.7 Recent Developments in Wastewater Treatment by Soils

The conventional system of surface or subsurface disposal of liquid waste cannot be applied in shallow soils over creviced bed rock. One possible alternative is to construct a disposal field in fill on top of the unsuitable soil called the mound system proposed by Wiltz, et.al.,(1970). The mound system has been proposed mainly for problem situations involving with (i) a high water table, (ii) a slowly permeable subsoil, and (iii) a shallow permeable soil above highly creviced bed rock.

Column studies on mound type disposal system for septic tank effluent in relation to (i) soil water and gas relations; and(ii) nutrient transformation and bacterial populations are reported by Magdoff,et.al. 1974). In their study they obtained complete removal of fecal indicators, the nearly complete COD removal and significant decrease in N and P concentrations. Mound systems, however have not been monitered under field conditions. Morever, their design was not based on an analysis considering basic physical and chemical processes associated with liquid waste disposal in soil. Studies on experimental mound system have been started by Bouma, et.al., (1973), but the results are not yet published.

3. SCOPE OF INVESTIGATION

From a review of the literature, it can be concluded that land disposal is neither a new or a noval idea. However, initially the purpose of land treatment approaches has emphasized wastewater disposal, whereas the current trend is towards not so much the disposal but the treatment and/or reuse. Presently more emphasize is being given to reclamation of wastewater and its recycle. Accordingly a lot of work is done in this context and a voluminous literature is available for the field, and laboratory column studies. But, still there are many parameters which were not taken into account in the previous studies and therefore proper design criteria could not be laid down. Moreover, most of the studies reported in literature were conducted only on coarse sand that accepted wastewater readily, but did not promote good and quick treatment. Furthermore, the information available in this area pertains to various soil types only from the U.S.A., and very few studies have so far been undertaken in this respect on Indian soils. The next task, therefore, is to determine what soil characteristics and hydraulic loading pattern will provide a reasonable balance between acceptance and treatment.

The present study was initiated to investigate the influence of particle size distribution, organic and

hydraulic loading rates, nature of feed suspension and its application technique. The study was undertaken along the following lines:

1. Preliminary Studies :

Preliminary column studies were planned to investigate the effect of particle size on wastewater treatment and its acceptance, using sand and Kanpur silt (Uttar Pradesh) in different proportions. Percolation rate observations were used to decide whether to continue or stop the wastewater application, and the regaining assimilative capacity of the soil systems.

2. Phase - I Studies:

From the preliminary studies, different soil compositions, which found to be suitable from wastewater treatment and acceptance point of view were selected for detailed study. Quality of the effluent, collected from columns of different soil composition, and soil depths, was monitored to check the treatment achieved. Percolation rate was taken as a parameter to decide whether to continue or stop the wastewater application to soil columns.

3. Phase-II Studies:

These studies were done on soil system which was found to be optimum from wastewater treatment and

acceptance rate point of view on the basis of Phase-I studies, to investigate the effect of loading rate. The loading rates were chosen from the literature (Robeck, et.al., 1964). Here also the quality of effluent, collected from columns which accepted different rates of loading, and soil depths, was monitored. Percolation rate was used as a parameter to decide whether to continue or to stop the wastewater application.

4. Phase-III Studies:

These studies were planned to evaluate the effect of initial chemical (alum coagulation) treatment to the wastewater on the effluent quality from soil columns, and the treatment capacity soil system.

4. MATERIALS AND METHODS

4.1 Materials

4.1.1 Soil :

The soils used in this study were Kanpur silt (U.P.) and sand. The grain size distribution of both these soils is given in Fig.4.1. In most of the studies the above two types of soils were mixed in different proportions. The physical and chemical characteristics of the soils used in this study are given in Table 4.1.

The particle size distribution for the sand and coarser silt particles was done by sieve analysis as given by Terzaghi, et.al. (1967). The pipette method using Anderson pipette was used for the determination of particle size distribution of finer silt.

Determination of soil organic matter was done using hydrogen peroxide as described by Jackson (1962). A known amount of oven dried (100-110°C)soil was saturated overnight with hydrogen peroxide, filtered through a Whatman No. 42 filter paper, washed several times with distilled water, dried in the oven at 100-110°C and final weight was taken. From the difference in weights, the organic matter was determined.

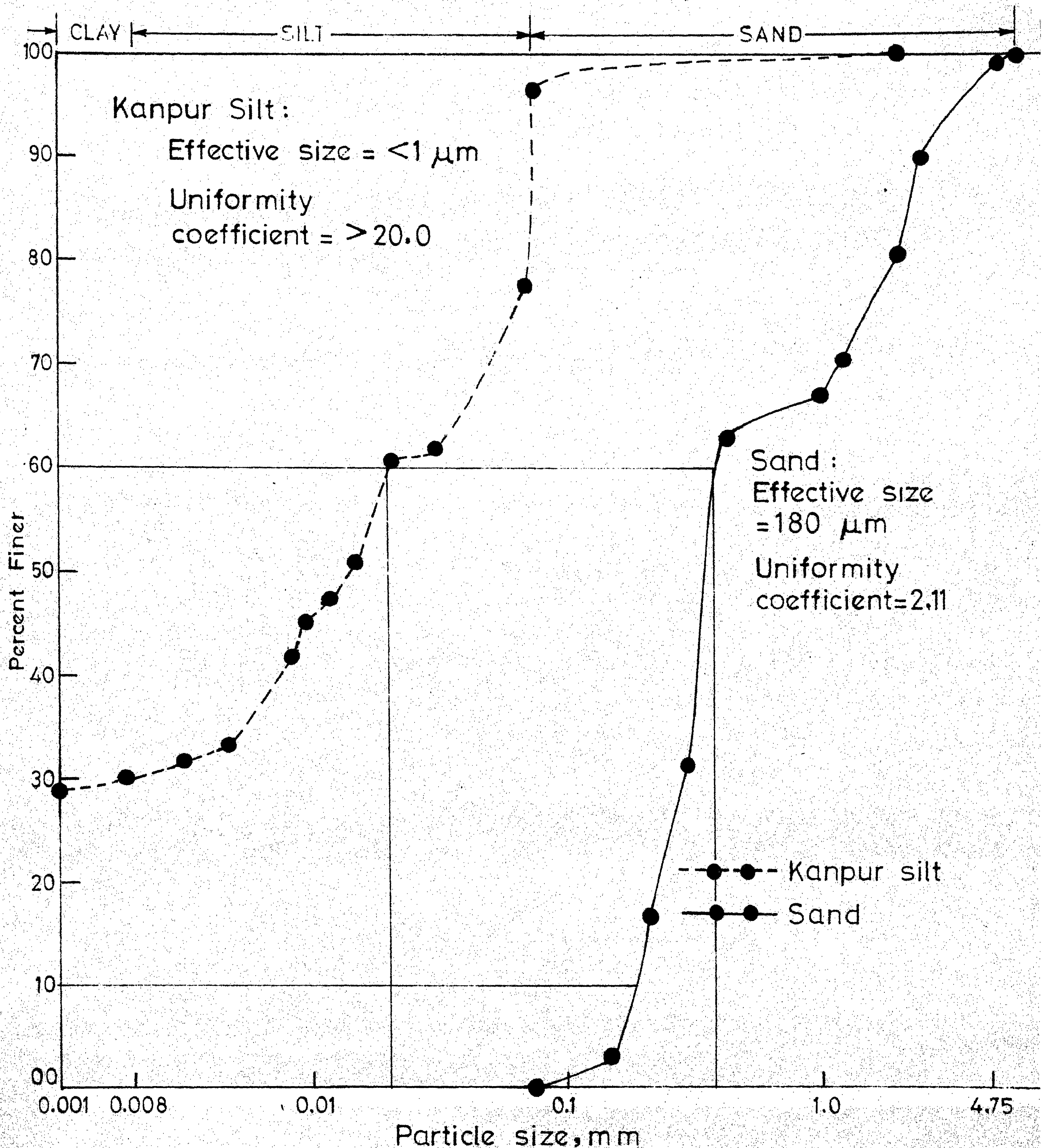

Fig. 4.1 Grain size distribution for Kanpur Silt and the Sand Used.

Percolation rate was determined using a method similar to the one recommended for septic tank percolation system (Indian Standard:2470-Part I, 1968).

TABLE 4.1

Physical and Chemical Characteristics of Soils

Characteristics	Sand	Kanpur Silt
Grain size distribution:		
Percent sand	100	3.50
Percent silt	--	66.50
Percent clay	--	30.50
φ C.E.C. in m. eq./100 gm	--	3.2
Specific gravity	2.65	2.50
Percent organic content	--	1.1
φ Constituents commonly found	Quartz, shell material	Illite, Quartz, Kaolinite
Percolation Rate, cm/day	15.42×10^3	18.52

φ Koya, K.V.A. (1975).

4.1.2 Wastewater:

The wastewater used in this study was raw domestic wastewater of IIT Kanpur Campus. The characteristics of this wastewater are presented in Table 4.2.

TABLE 4.2

Characteristics of Raw Waste water

Characteristics	Minimum value	Average value	Maximum value
pH	7.8	7.9	8.1
Turbidity, NTU	20.0	45.0	89.0
Conductivity, mhos/cm.	--	1.5×10^{-3}	--
C.O.D. mg/lit	67.2	120.0	230.0
C.O.D. to B.O.D. ratio	--	1.25	--
Ammonia Nitrogen-N, mg/lit.	13.0	17.60	21.5
Total Nitrogen-N, mg/lit.	16.0	24.30	30.75
Total Phosphate-P, mg/lit.	6.3	8.9	11.0
Total Alkalinity as $CaCO_3$, mg/lit.	--	430.0	--
Total Coliforms, No./ml.	4.5×10^3	20.4×10^3	39.7×10^3

4.2 Methods

4.2.1 Experimental Techniques:

4.2.1.1 Preparation of soil columns:

Most of the column studies were done in cylindrical perspex columns of 7.5 cms (3'') diameter provided with a perforated perspex plate at the bottom as shown in Fig. 4.2. Columns of different heights were made, and filled with soil

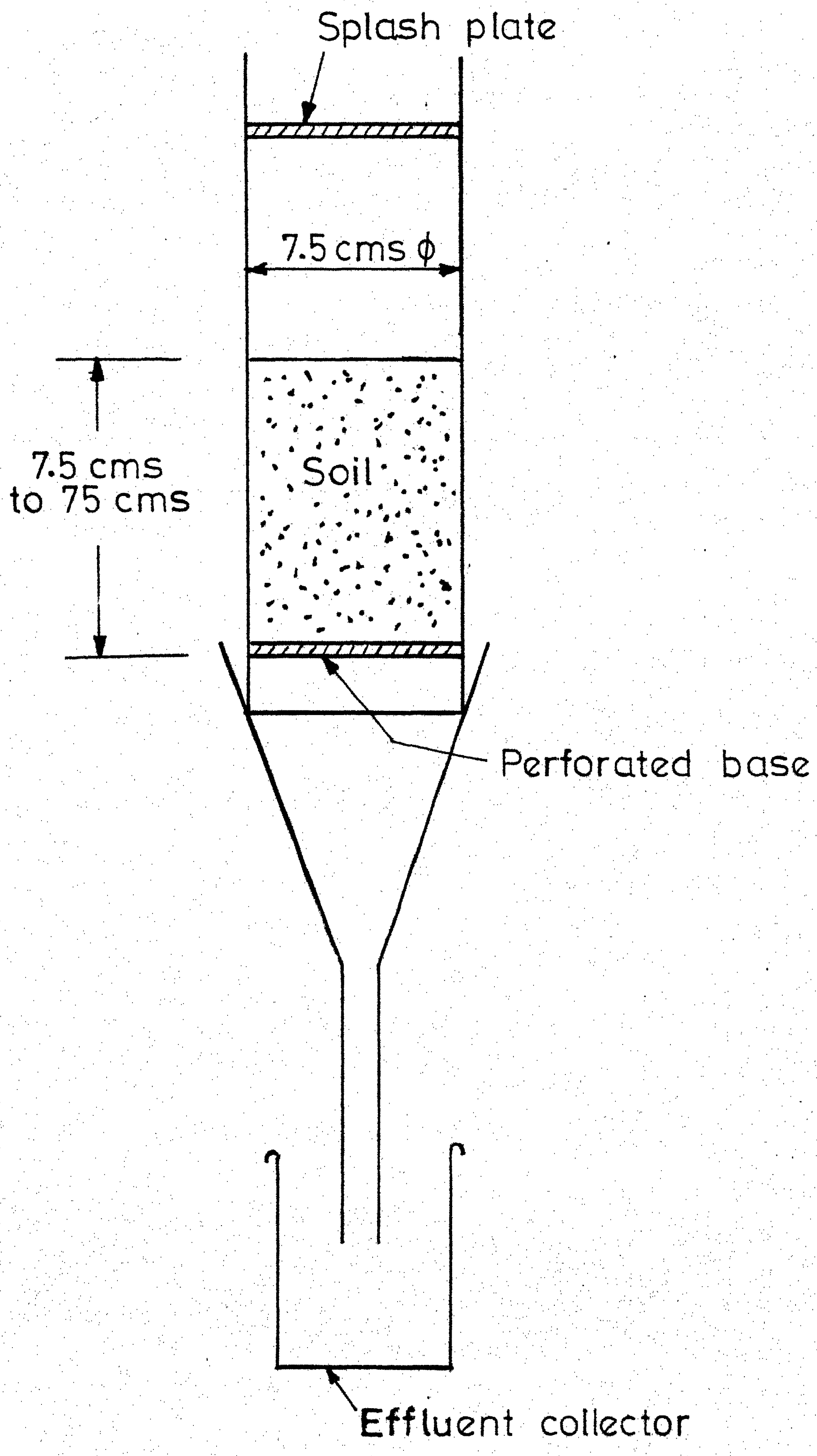

FIG.4.2 CROSS SECTION OF A TYPICAL SOIL COLUMN.

so as to get the desired thickness of the soil bed. Columns were conditioned by saturating them several times with tap water prior to application of wastewater.

4.2.1.2 Application of Wastewater:

The application of wastewater to each column varies as to pattern, amount and method. Most of the columns, however, were fed once -a-day with the predetermined volume depending on the rate of loading, poured onto a splash plate at a rate sufficient to flood the surface within a few seconds. The splash plate as shown in Fig. 4.2 was used to assure uniform distribution of wastewater and to avoid suspension of soil particles by turbulance. Some columns were dosed 3 or 5 times-a-day depending upon the desired rate of loading. The total period of daily dosing ranged from 30 to 90 days.

4.2.1.3 Preliminary Studies:

Preliminary studies were done on six perspex columns of 7.5 cms (3'') diameter. The depth of the soil bed was kept to 75 cms. This depth was chosen because from the literature (Day, et.al., 1972), it was found that below this depth no appreciable treatment is achieved. The soil used in the columns was a mixture of sand and Kanpur silt in different proportions. The proportions used are given in Table 4.3.

TABLE 4.3

Different Proportions of Sand and Kanpur silt Used.

Soil Type	Percent Sand	Percent Kanpur Silt
Soil I	100	00
Soil II	80	20
Soil III	60	40
Soil IV	40	60
Soil V	20	80
Soil VI	00	100

The above proportions were on the basis of oven dried (100-110°C) weight. The application of waste-water was done once in a day at the rate of 0.048 cu.m./sq.m/day (1 gpd/sq.ft) as described earlier. Studies were continued for 30 days.

4.2.1.4 Phase-I Studies:

Effect of mixing silty soil with sand :- These studies were conducted by choosing three proportions of sand and Kanpur silt. The proportions used were (i) 100 percent sand, (ii) 80 percent sand and 20 percent Kanpur silt, and (iii) 60 percent sand and 40 percent Kanpur silt. The soils

were named as soil I, soil II and soil III respectively for further discussions. The grain size distribution for these three soils is given in Fig. 4.3. The above proportions were chosen on the basis of preliminary studies. In all 15 columns, five of each soil, with various depths of soil bed were used. The depths of soil bed adopted were 7.5 cms, 15 cms, 30 cms, 45 cms and 75 cms.

After conditioning the soil columns as described earlier, columns were loaded with wastewater for 30 days. The columns were dosed once a day at the loading rate of 0.048 cu.m./sq.m./day (1 gpd/sq.ft.) obtained from the literature (Thomas, et.al., 1969). Wastewater was applied to the splash plate as stated earlier. Influent and effluents were analysed for COD, Ammonia-nitrogen, Total-nitrogen, Nitrite-nitrogen, Phosphates and Total coliforms on alternate days.

4.2.1.5 Phase-II Studies:

Effect of loading rate:- These studies were done with soil III (60 percent sand and 40 percent Kanpur silt) as this was found suitable from Phase-I studies. Once again 15 columns, three each of 7.5 cms, 15 cms, 30 cms, 45 cms and 75 cms soil depth were used. Columns were conditioned with tap water as described earlier. Five columns were loaded at the rate of 0.096 cu m./sq.m/day (2 gpd/sq.ft.)

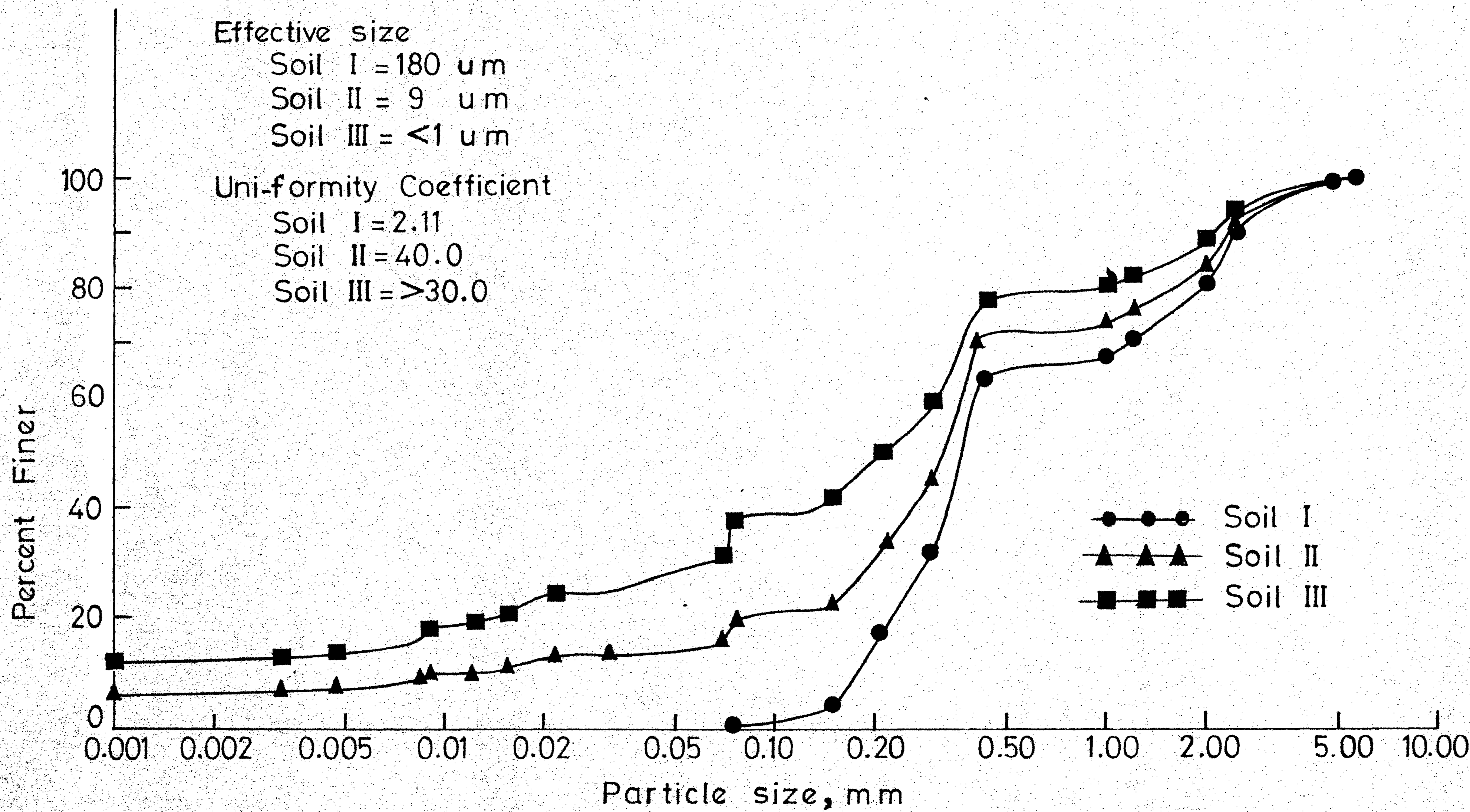

FIG. 4.3 GRAIN SIZE DISTRIBUTION FOR THREE MIXED SOILS.

applied twice a day; another five columns with the rate of 0.144 cu.m./sq.m./day (3 gpd/sq.ft.) applied thrice a day, and remaining five columns with the rate of loading of 0.24 cu.m./sq.m./day (5 gpd/sq.ft.) applied five times a day. The columns were loaded continuously for 37 days. The column influent and effluents were analysed for COD, ammonia-nitrogen, total-nitrogen, nitrite-nitrogen, phosphate and total coliforms. All the analyses were done on alternate days. Percolation rates were observed when the hydraulic failure occurred.

4.2.1.6 Phase -III Studies:

Effect of initial Treatment to wastewater:- In order to see the effect of initial treatment on wastewater two glass columns of 2.54 cms (1'') diameter were used. One column was filled with Soil I and other with soil III. Depth of soil in both the columns was kept to 45 cms. The wastewater was applied after coagulation at the rate of 0.24 cu.m./sq.m./day (5 gpd/sq.ft.). The wastewater application was continued for 90 days. The influent and effluents were analysed for all parameters after every five days.

Initial treatment:- Initial treatment given to wastewater was that of alum coagulation. Optimum dose of alum was determined from Jar Test. Every time alum coagulation of raw wastewater was done at optimum dose (200 mg./lit.)

with 1 minute of rapid mixing at 100 RPM followed by 30 minutes slow mixing at 20 RPM and 30 minutes settling in a two litre flask.

4.2.2 Analytical Techniques:

The analytical techniques, used in this study are mostly those given in Standard Methods (1971). A few other methods are also used which are briefly explained in this section.

4.2.2.1 Instruments:

The instruments used in the various analyses are listed below. Common instruments are not included in the list.

1.	Anderson Pipette :	Instrument Division, Fisher Scientific, Pittsburgh, P.A.
2.	Kjeldal Apparatus:	Narang Scientific Works, New Delhi
3.	pH meter :	Expanded scale pH meter Type 331, CYSTRONICS, 89-92, Naroda Industrial Area, Ahmedabad 382330.
4.	Spectrophotometer: (Spectronics 20)	Bausch and Lomb Inc. Rochester, New York, U.S.A.
5.	Jar Test Apparatus:	Phipps and Bird Inc., Richmond, Virginia.
6.	Turbidity meter:	Hach Turbidity meter, Model 2100 A Hach Chemical Company.

4.2.2.2 Sampling and Analysis:

In most cases the samples for analyses were collected in the morning, however, to ascertain the

variation in the results, some samples were collected during other times also. Whenever samples were analysed after some lapse of time, such samples were preserved as described in Standard Methods (1971). The various analytical methods used in this study are given below:

(i) Alkalinity (Total, Carbonate and bicarbonate): Various forms of alkalinity were determined by titrimetric method specified in Standard Methods (1971). The indicators used were phenolpthalein and methyl orange.

(ii) Bio-chemical Oxygen Demand (BOD): BOD determination was done as per Standard Methods (1971) using appropriate dilutions.

(iii) Chemical Oxygen Demand (COD): COD analyses was regularly conducted as per the method given in Standard Methods (1971). A sample volume of 20 ml or fraction diluted to 20 ml was used for the analyses.

(iv) Nitrogen-Ammonia: Direct Nesslerysation method as given in Standard Methods (1971) was used for the measurement of ammonia-nitrogen. Standard curves were drawn for each set of reagents and checked during each analyses Ammonium Chloride was used for preparing the Standard curves. Wave length of 420 nm with light path of 1.875 cms (3/4'') was used for ammonia determination.

(v) Nitrogen-Nitrite: Nitrite-Nitrogen was determined as per the procedure given in Standard Methods (1971). A wave elength of 520 nm at light path length of 1.875 cms. was used.

(vi) Nitrogen-Total: Total nitrogen was determined by digestion method proposed by Thompson, et.al., (1951). The method is as follows:

In a 100 ml kjeldal flask, 10 ml of the sample (containing 5-200 μg of nitrogen) was taken, to which 4 ml. of 3 N sulfuric acid were added. Glass beads were added to avoid bumping. The digestion was carried out for 10 minutes after the white fumes started appearing. After cooling, contents of the kjeldal flask were transferred to a 50 ml beaker and the pH was adjusted to about 7.0 with 1.25 N sodium hydroxide. Total volume was made upto 25 ml in a standard volumetric flask. 10 ml or aliquot diluted to 10 ml was taken for Nesslerisation. Nesslerization was done as given previously for ammonia-nitrogen.

(vii) pH :pH was directly measured using a pH meter.

(viii) Phosphate (Total): Sample preparation and digestion was done according to sulfuric acid-nitric acid digestion method and analysis was done as per stannous chlorine method. Both these steps are given in Standard

Methods (1971). A wave length of 690 ηm was used with light path length of 1.875 cms. Standard curve was prepared with potassium dihydrogen phosphate as standard.

(ix) Total Coliforms: Total coliforms count was done on EMB agar as given in Standard Methods (1971).

(x) Turbidity: Turbidity was directly measured by turbidity meter, by checking every time with standard turbidity suspension.

5. RESULTS AND DISCUSSIONS

This study was conducted in three different phases following the preliminary studies. The objectives of preliminary and the following three phases of the study are given in Chapter 3 and the methods adopted are given in Chapter 4. The studies were basically confined to the development of soil system and hydraulic loading pattern for the treatment of domestic and pretreated wastewater. The results obtained in the phases of the study are presented and discussed separately.

5.1 Preliminary Studies

As an initial step towards developing a suitable soil system for the treatment of domestic wastewater, which in turn depends on the particle size distribution of the soil component, sand and Kanpur silt were mixed in different proportions. Perspex columns of 75 cms soil depth with different proportions of above mentioned soils were used for this study. Wastewater was applied to each soil column at the rate of 0.048 cu.m./sq.m./day (1 gpd/sq.ft.). This rate of loading was chosen because it was used and found to be suitable in the previous laboratory and field studies (Robeck, et.al., 1964; and Thomas, et.al., 1969). Hydraulic efficiency was measured by the percolation rate and was used

as a criterion to decide hydraulic failure, i.e., the point at which a liquid dose fails to infiltrate completely before the next dose is delivered as suggested by Schwartz, et.al., (1970).

The observed percolation rates at three different stages are given in Table 5.1.

TABLE 5.1

Observed Percolation Rates

Soil Type	Soil Composition: Percent sand	Soil Composition: Percent Kanpur silt	Initial percolation rate cms/day	Percolation Rate after 30 days of ww application cms/day	Percolation after 15 days of Rest period cms/day
Soil I	100	00	15.43×10^3	15.18×10^3	15.3×10^3
Soil II	80	20	579.2	420.1	560.3
Soil III	60	40	144.2	92.0	128.0
Soil IV	40	60	31.4	4.8	10.1
Soil V	20	80	22.0	φ	6.9
Soil VI	00	100	18.52	φ	5.2

φ Not measurable.

From the above Table, it is clear that if the silt content, i.e., finer fraction (-75 μm) is more than 40 percent, then

the percolation rate is reduced drastically. Moreover reduction in percolation rate is further enhanced by the wastewater application, reduction increasing as the percent finer fraction (-75 μm) increases.

Thus, from these results it can be concluded that if a particular soil contains finer fraction (-75 μm) greater than 40 percent, then it is not feasible to apply wastewater to such a soil, since the wastewater acceptance rate is very less as reflected by the percolation rate. Further the increase in percolation rate after 15 days of rest period is not significant if the soil contains more than 40 percent finer fraction (-75 μm).

Though, in the preliminary studies more emphasize was given to the wastewater acceptance rate, intermittant check on effluent quality from the soil columns indicated that as the finer fraction increases, effluent quality improves to a great extent. Therefore, further studies (Phase-I Studies) were planned to see the effect of finer fraction on the purification of wastewater achieved.

5.2 Phase-I Studies

In this study only soil I, soil II, and soil III were taken as they were found suitable from wastewater acceptance rate point of view from the preliminary

studies. The loading rate used was 0.043 cu.m./sq.m/day (1 gpd/sq.ft.) obtained from the literature (Robeck, et.al., 1964; and Thomas, et.al., 1969). In all 15 columns were used with 7.5 cms, 15 cms, 30 cms, 45 cms and 75 cms soil depth with each of the above mentioned soil type. The influent and effluents were regularly analysed for C.O.D. Phosphates, Ammonia-Nitrogen, Total Nitrogen and Total coliforms. Nitrite determinations were also done intermitantly to check the extent of nitrification through soil columns. The degree of treatment achieved with respect to all above parameters at various depths of soil and with each soil type under consideration is given and discussed considering each parameter separately as follows:

C.O.D. Removal: Figs.5.1 to 5.5 show the C.O.D. variation in the influent and effluent from soil columns of various soil types, namely, soil I, soil II and soil III, and of different soil depths. The influent C.O.D. varied from 67.2 mg/lit. to 230 mg/lit. with an average value of 120 mg/lit. The C.O.D. removal ranged from about 60 to 100 percent (For detailed results see Appendix-Table 1). From the graphs it is clear that C.O.D. removal is almost same irrespective of the soil type, with slightly better C.O.D. removal in soils, having higher percent finer (-75 μm) fraction. Maximum

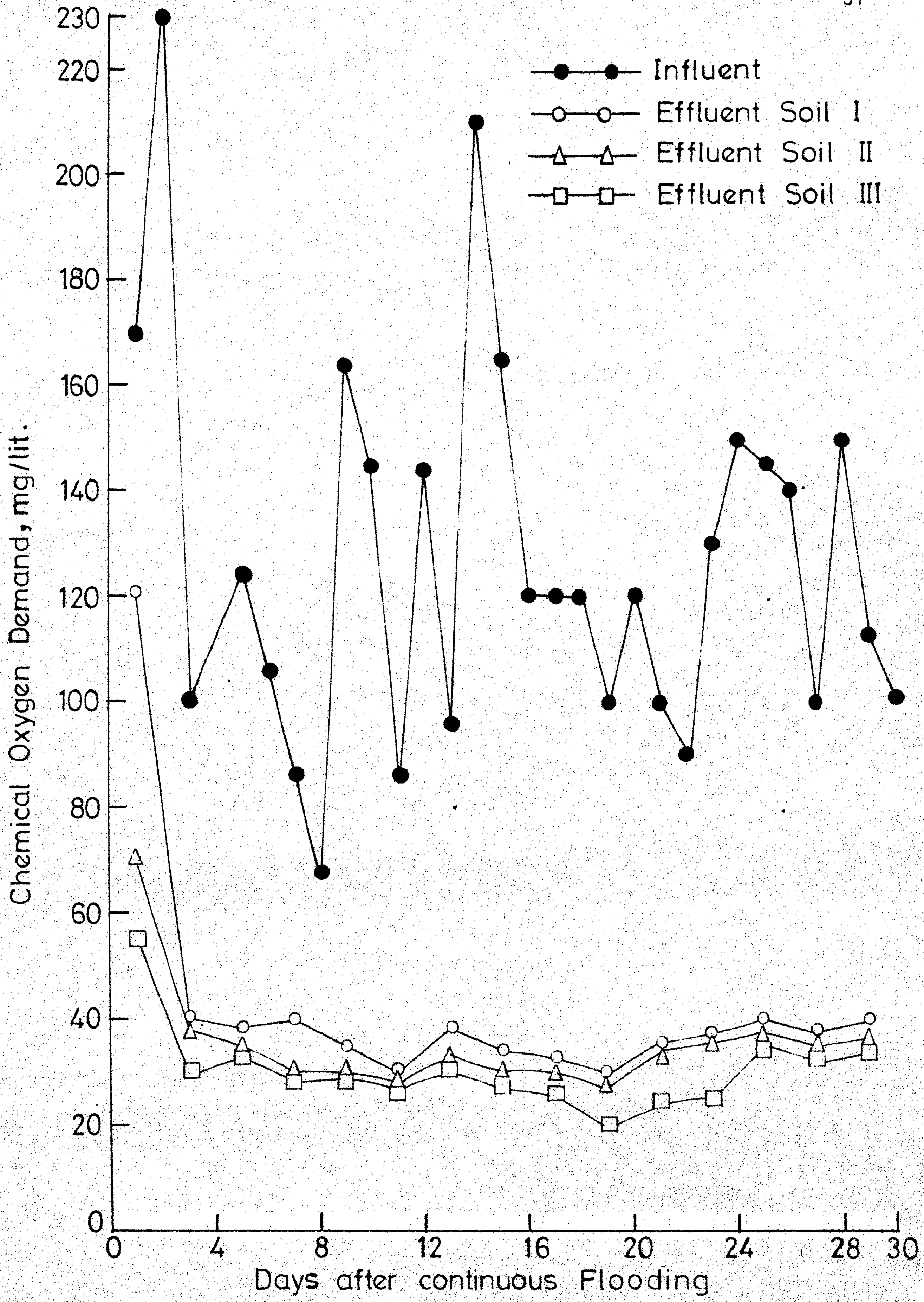

FIG.5.1 CHEMICAL OXYGEN DEMAND OF INFLUENT AND EFFLUENT FROM 7.5 cms. SOIL COLUMNS.

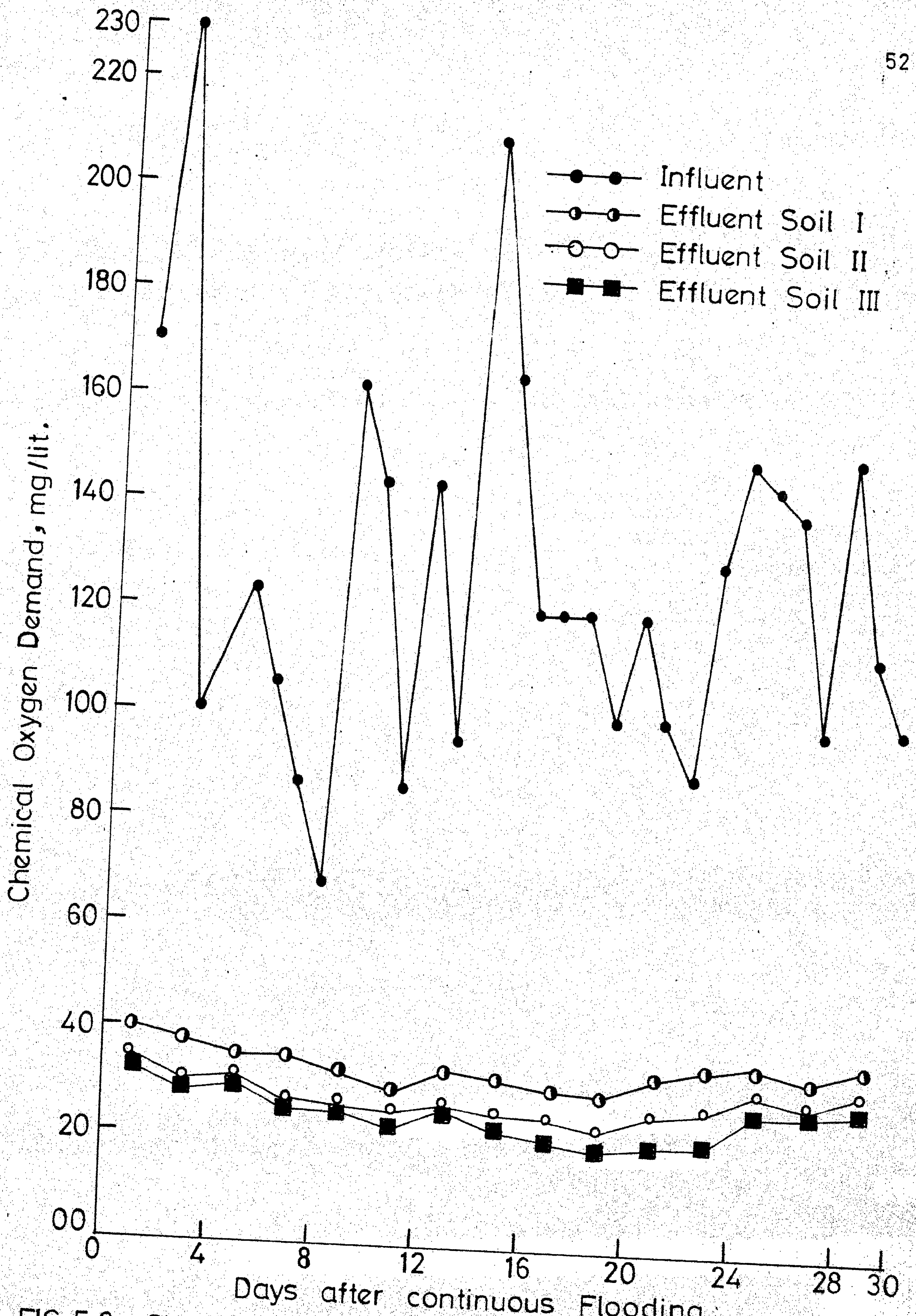

FIG. 5.2 CHEMICAL OXYGEN DEMAND OF INFLUENT AND EFFLUENT FROM 15 cms SOIL COLUMNS.

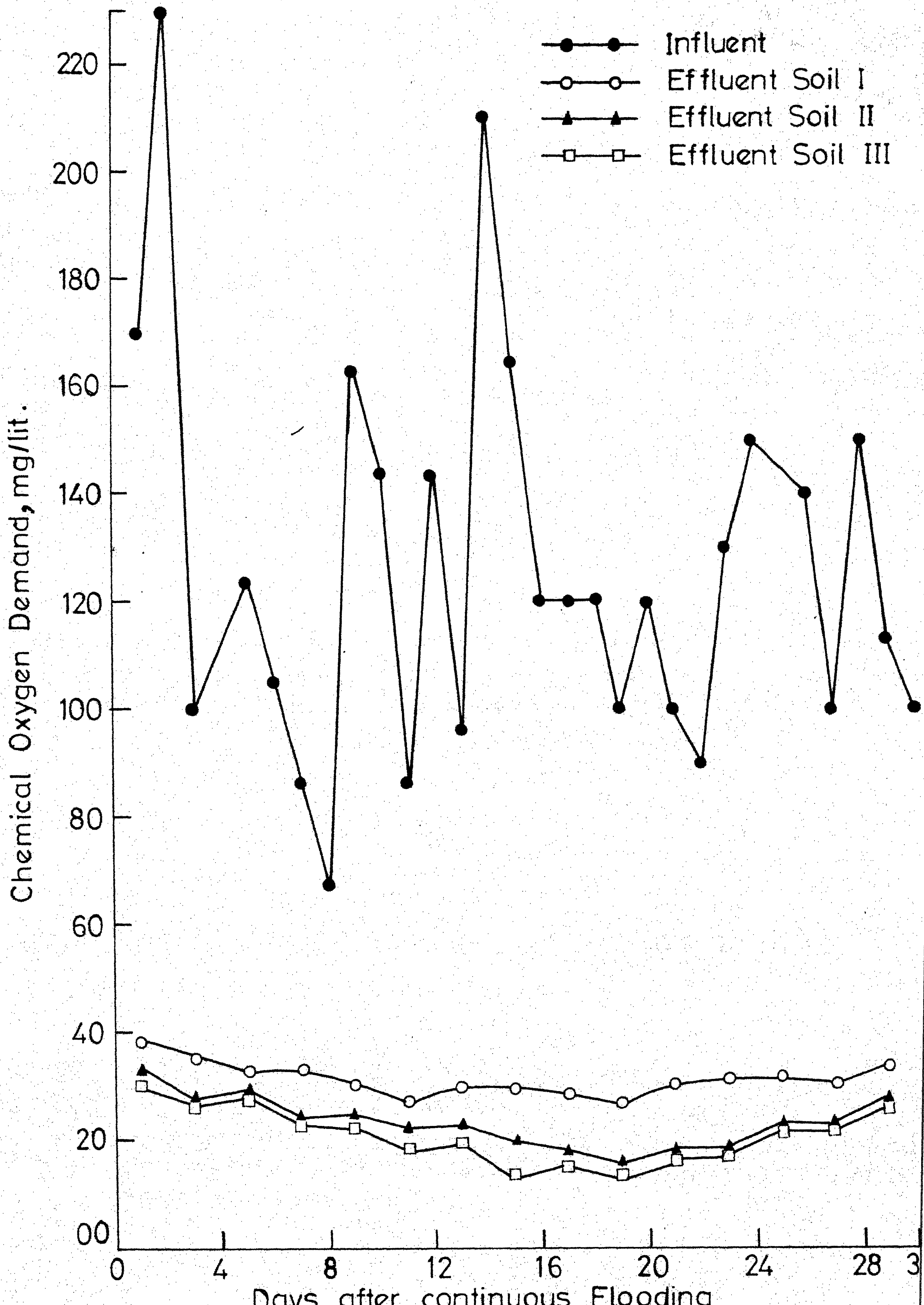

FIG. 5.3 CHEMICAL OXYGEN DEMAND OF INFLUENT AND EFFLUENT FROM 30 cms. SOIL COLUMNS.

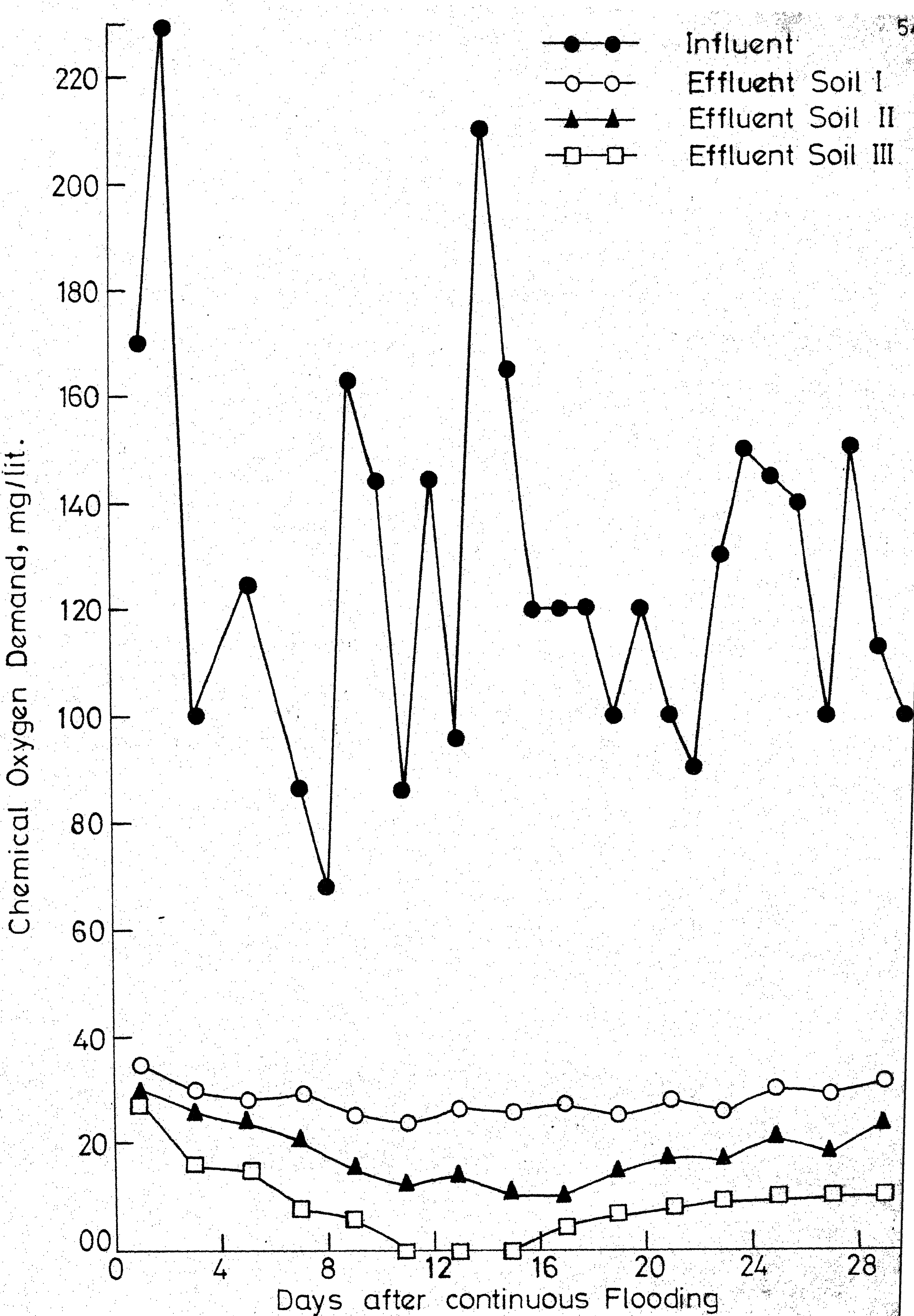

FIG.5.4 CHEMICAL OXYGEN DEMAND OF INFLUENT AND EFFLUENT FROM 45 cms. SOIL COLUMNS.

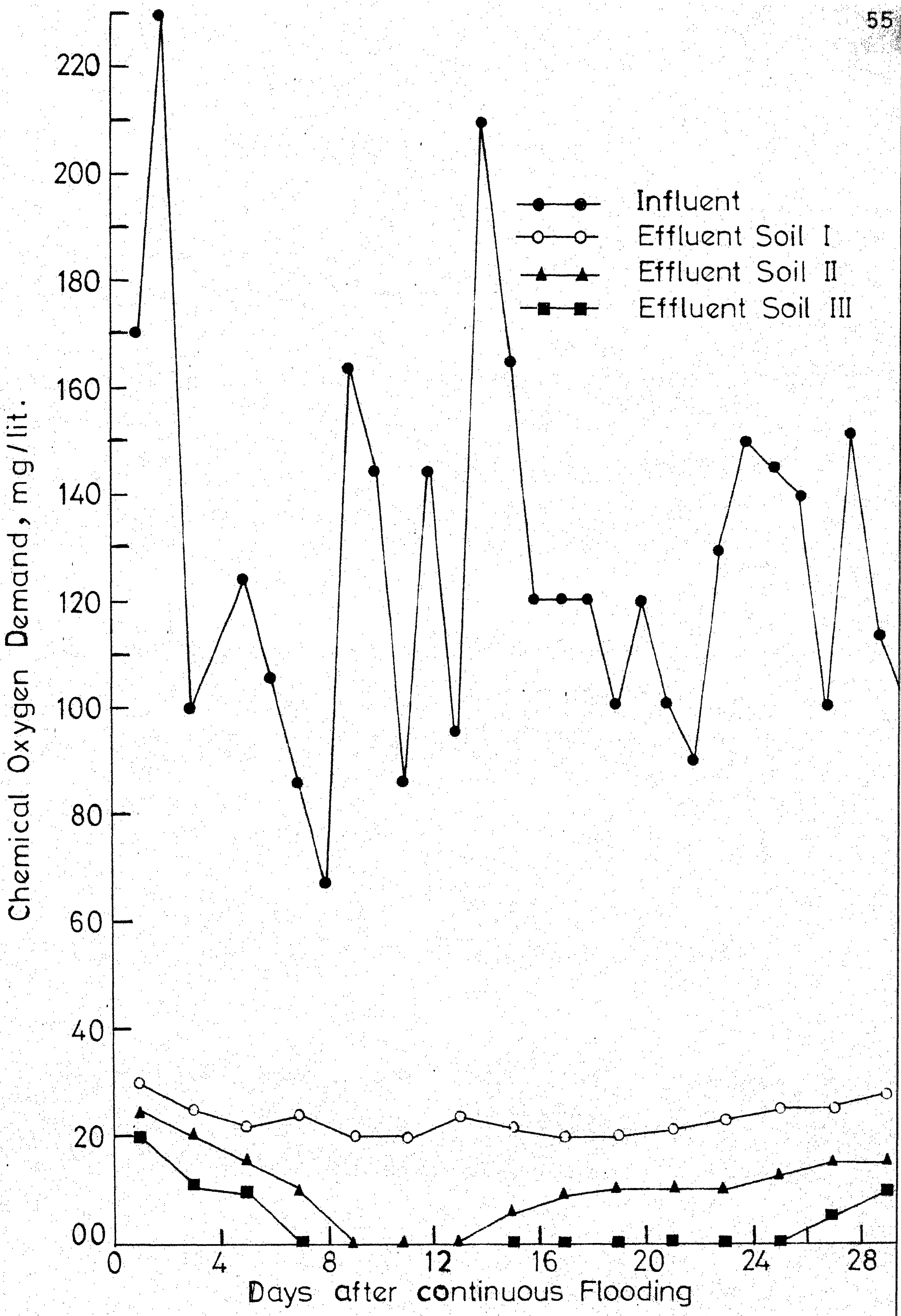

FIG. 5.5 CHEMICAL OXYGEN DEMAND OF INFLUENT AND EFFLUENT FROM 75 cms. SOIL COLUMNS.

C.O.D. removal occurred in the top 15 cms of soil depth and it is almost negligible below 45 cms of soil depth. Most of the C.O.D. removal may be due to biological degradation of organics under aerobic conditions as sufficient oxygen would be available in the soil environment as against the oxygen required for microbial consumption (Magdoff, et.al., 1974). This explanation is further supported by the observation that C.O.D. removal is almost same irrespective of the soil type and thus is independent of the grain size distribution, sorptive and ion exchange capacity of soils. However, small portion of C.O.D. removal may be due to screening of particulate organics and sorption on soil constituents or both (Magdoff, et.al., 1974). Thus this might be the reason of slightly better C.O.D. removal from soil columns having higher percentage of Kanpur silt.

Phosphate Removal : Fig. 5.6 shows the phosphate concentration in influent and effluent from soil columns of various soil types and of different soil depths (for detailed results see Appendix- Table 2). The influent phosphate concentrations varied from 6.2 mg/lit. to 11.0 mg/lit. with an average value of 8.9 mg/lit. No measurable concentration of phosphate was obtained in effluents from columns with depth of soil 15 cms and more with soil II and soil III. However, with soil I, 1-2 mg/lit of phosphate concentration was found in

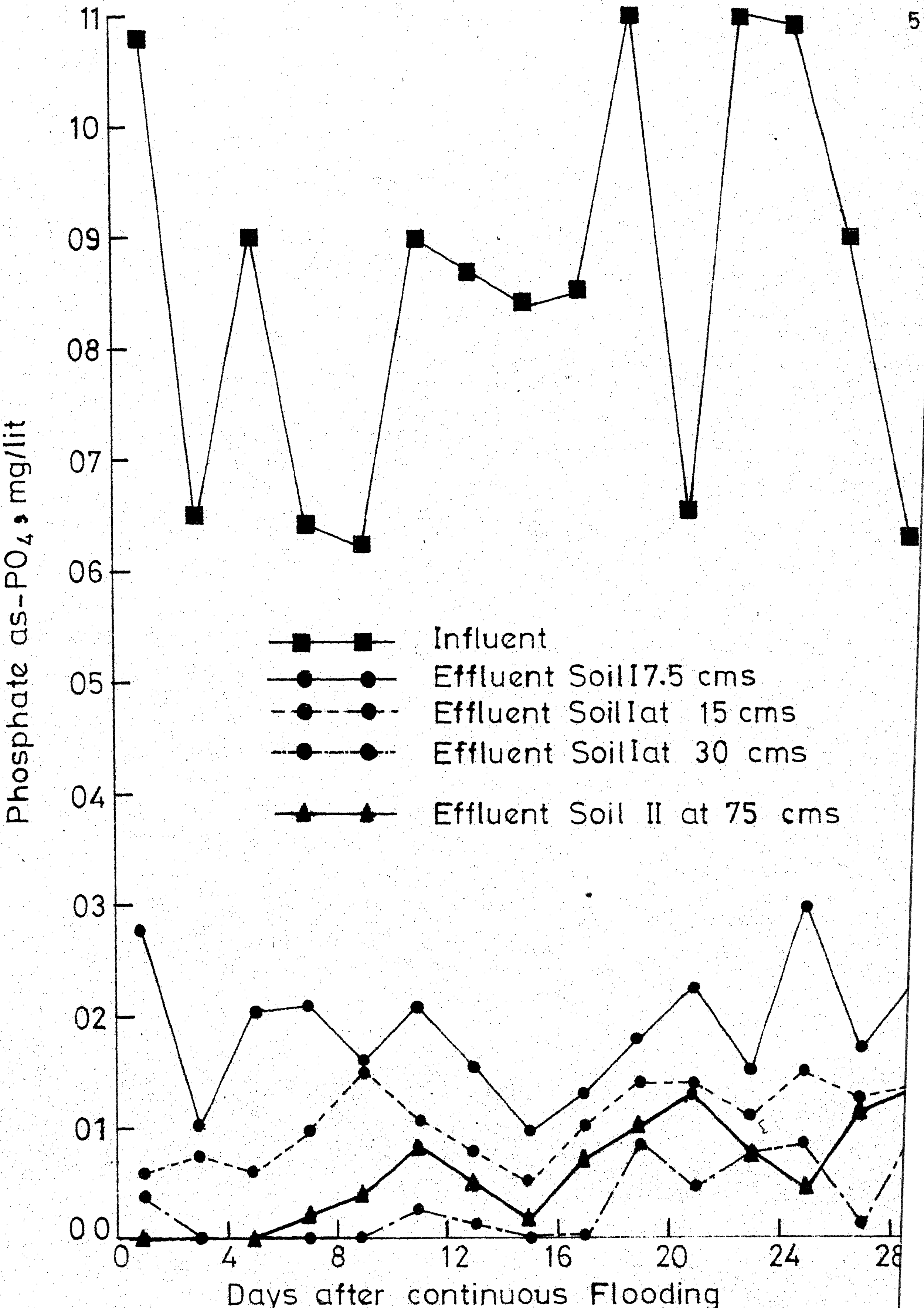

Fig. 5.6 Phosphate Cocentration of Influent and Effluer
From Soil Columns.

effluents from columns of even 30 cms soil depth. From Fig. 5.6 it can be seen that phosphate concentration in the effluent, to some extent, depends on the influent phosphate concentration. Sorption is probably responsible for phosphate removal from soils having more percent finer fraction. The rate of phosphate sorption on soils is reported to be very slow (Sawhney, et.al., 1975), which might be the reason of less phosphate removal in soil I, as soil I has high percolation rate and hence allows less contact time. Sawhney (1977) found that phosphate can be removed to the extent of sorptive capacity of soil and after that it would appear in the effluent, but the findings of Lance (1977) indicated that phosphates can be removed even after saturation sorptive capacity of soils by precipitation and, thus, there would not be any danger of phosphates remaining in the effluent.

Ammonia and Total Nitrogen Removal : Figs. 5.7 to 5.11 show the ammonia and total nitrogen variations in influent and effluent from columns of various soil types and different soil depths. The detailed observations are presented in Appendix-Table 3 and 4. The influent ammonia nitrogen varied from 13.0 mg/lit. to 21.5 mg/lit. with an average value of 17.60 mg/lit. and total nitrogen ranged from 16.0 mg/lit. to 30.75 mg/lit. with an average value of 24.30 mg/lit.

From the Figs.5.7 to 5.11, it is clear that ammonia and total nitrogen removal, to a great extent, depends on soil type. Almost complete removal of ammonia nitrogen occurred in top 15 cms with soil III, while with soil II the same removal occurred in top 30 cms, and the ammonia nitrogen concentration remained in the effluent of columns with soil I of even 45 cms soil depth. Thus, from this it can be concluded that ammonia nitrogen removal depends on the particle size distribution, sorptive and ion exchange capacity of soils as soil I, soil II and soil III have different particle size distribution, and different sorptive and ion exchange capacities. The total nitrogen removal, more or less follow the trend of ammonia nitrogen removal, however the removal is not 100 percent. From Figs.5.10 and 5.11 it can be seen that total nitrogen concentration is more in effluents from columns of 75 cms depth than in the effluents of columns of 45 cms soil depth. This might be due to fixation of nitrogen by nonsymbiotic microorganisms, those living freely and independently in the soil. Non symbiotic nitrogen fixation has been studied (Pelczar and Reid, 1965) extensively with Clostridium pasteurianum. This is an anaerobic bacillus, and there is an every possibility of anaerobic conditions to exist in 45 cms to 75 cms depth of soil zone in the columns. However, this finding needs

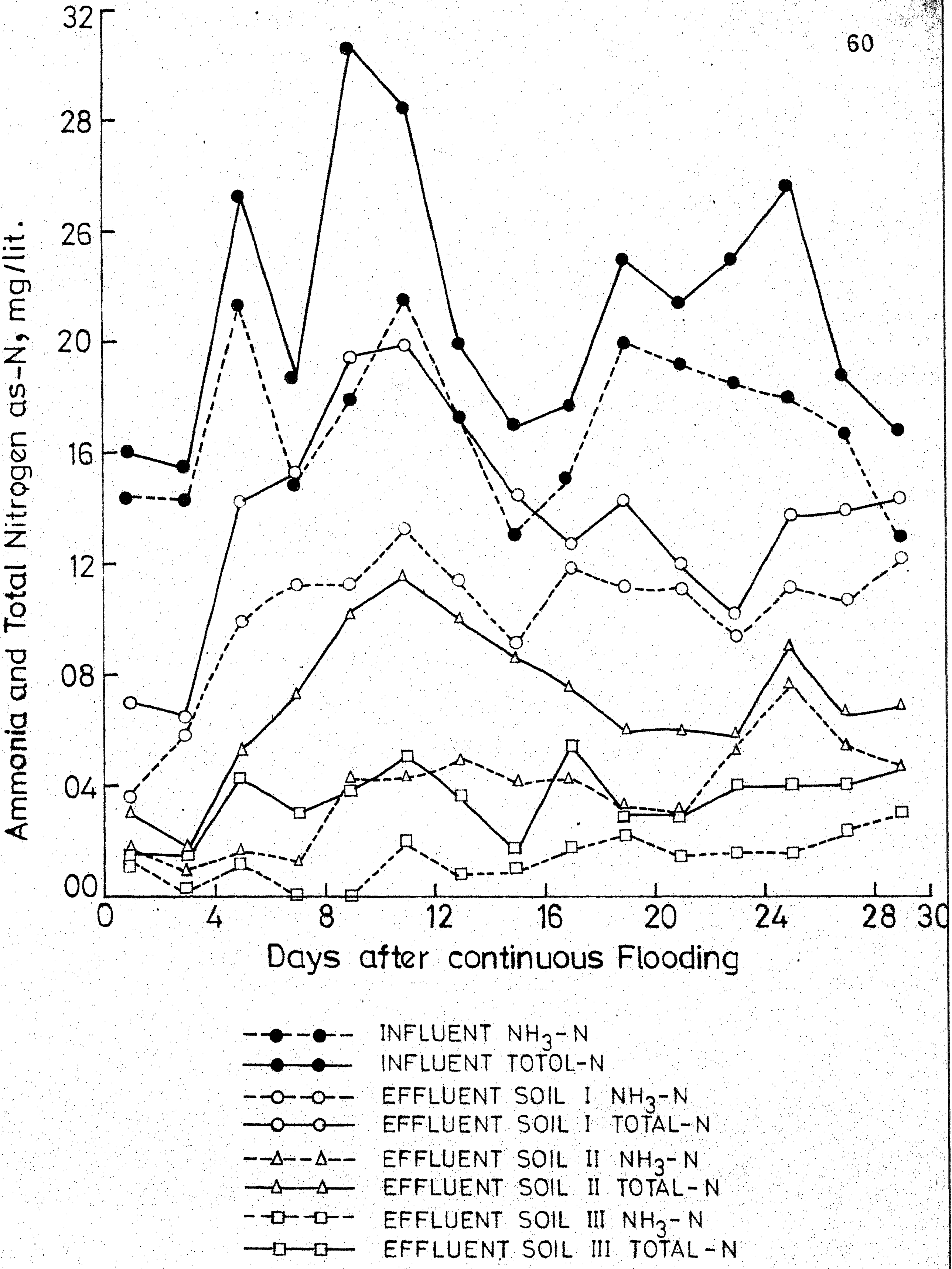

FIG.5.7 AMMONIA AND TOTAL NITROGEN OF INFLUENT AND EFFLUENT FROM 7.5cms. SOIL COLUMNS.

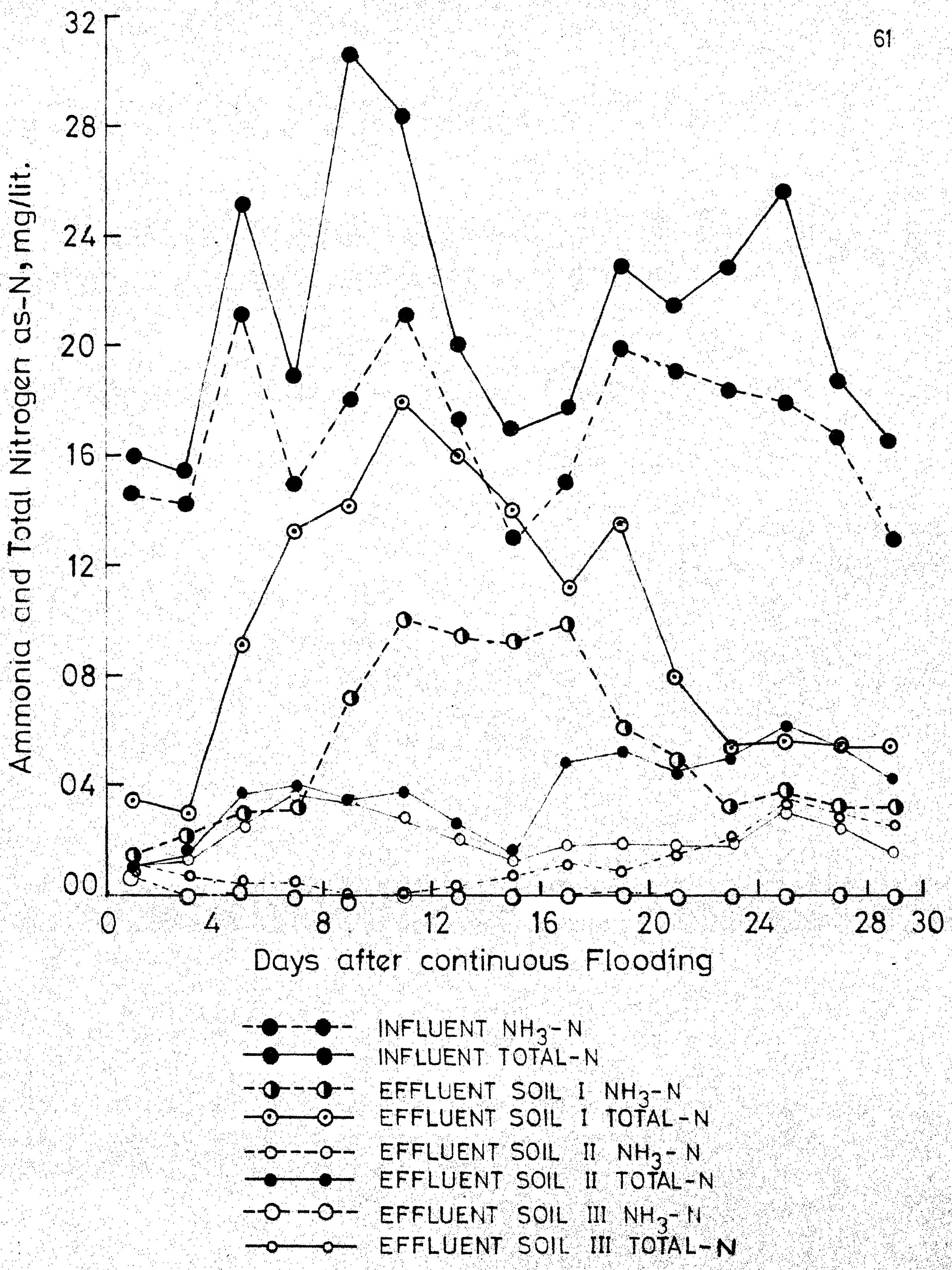

FIG.5.8 AMMONIA AND TOTAL NITROGEN OF INFLUENT AND EFFLUENT FROM 15 cms SOIL COLUMNS.

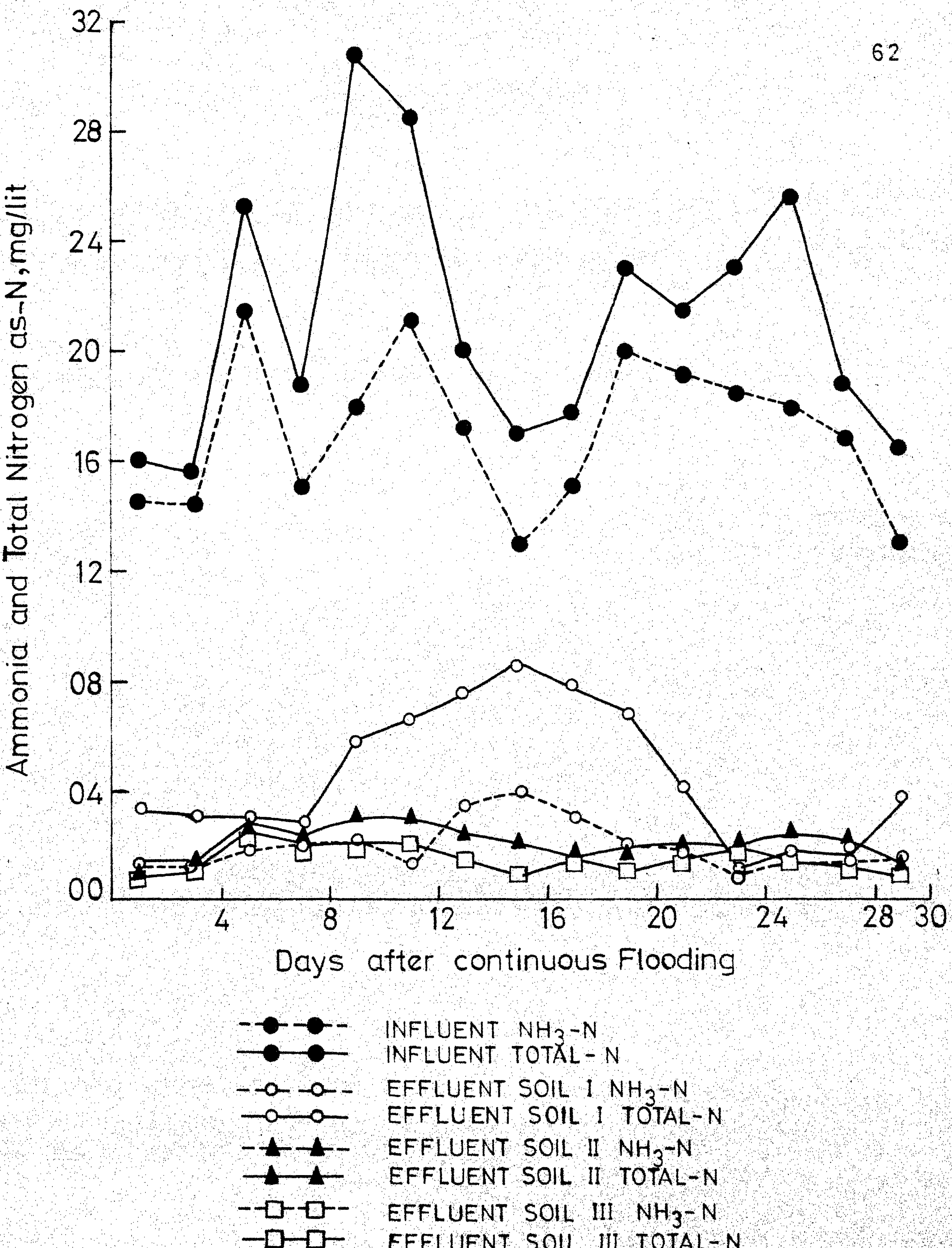

FIG. 5.9 AMMONIA AND TOTAL NITROGEN OF INFLUENT AND EFFLUENT FROM 30cms. SOIL COLUMNS.

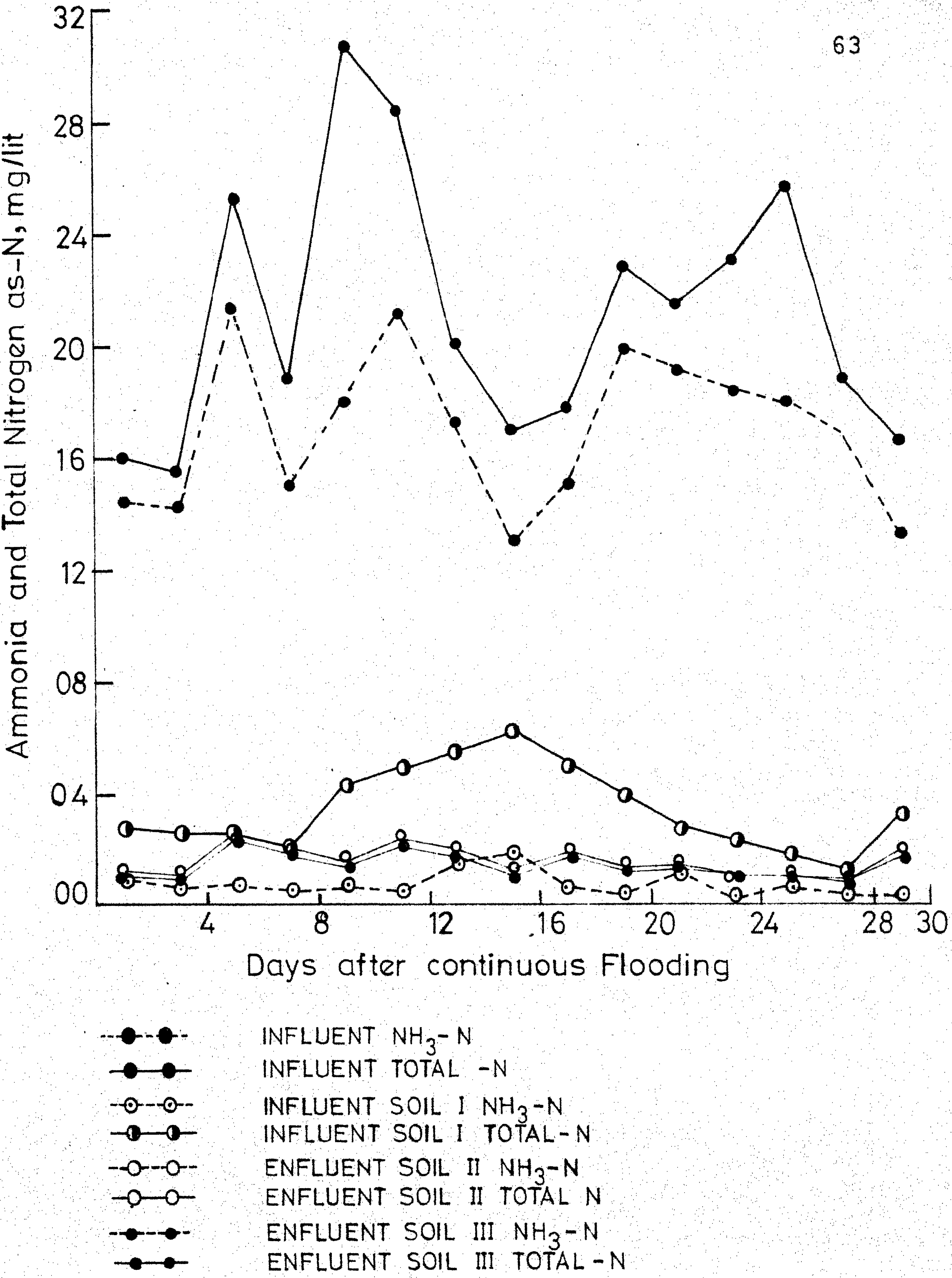

FIG.5.10 AMMONIA AND TOTAL NITROGEN OF INFLUENT AND EFFLUENT FROM 45cms SOIL COLUMNS.

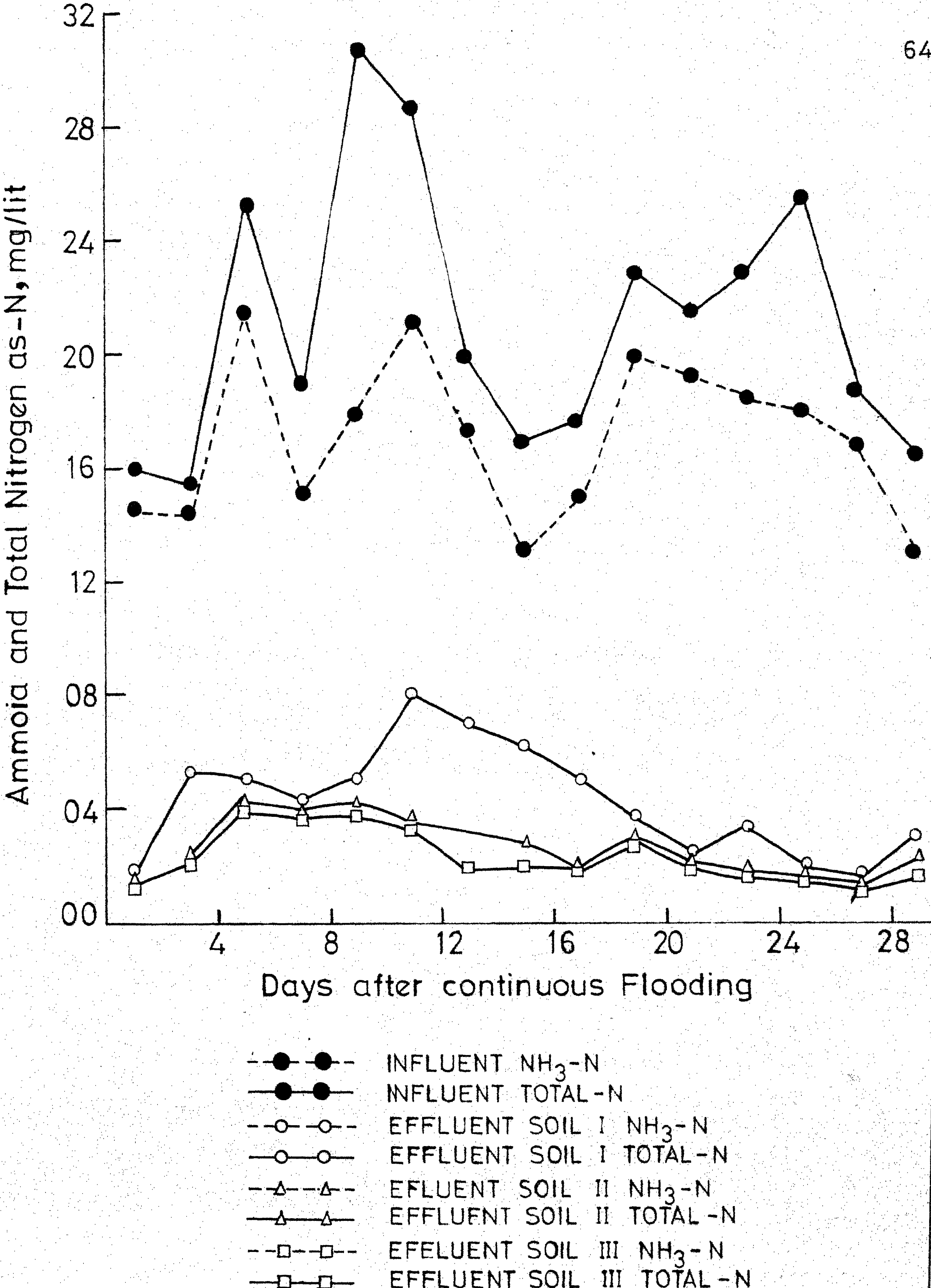

FIG.5.11 AMMONIA AND TOTAL NITROGEN OF INFLUEN AND EFFLUENT FROM 75 cms. SOIL COLUMNS

to be confirmed in greater details by performing further experiments.

The following processes can be considered in attempting to account for the N removal from the wastewater by soil columns : (i) nitrification; (ii) volatilization of NH_3; (iii) adsorption of NH_4^+ by the clay and silt fraction; (iv) incorporation into microbial tissue; and (v) adsorption of NH_3 by organic matter.

Ammonia could be volatilized, since the wastewater entered the columns at pHs between 7.8 to 8.1. Some N undoubtedly would be incporated into microbial cells, but removal by this mechanism will be limited by the available carbon. The C.O.D. of the wastewater was reduced from 120 mg/lit. to 20 mg/lit., which is equivalent to the removal of approximately 30 mg/lit. of carbon. Since the C/N ratio of microbial tissue varies between 5:1 and 10:1 (Lance and Whisler, 1972) a maximum of 6 mg/lit. N could be incorporated into microbial tissue. The actual amount would be much less than 6 mg/lit. because some of C will be lost as CO_2, as a consequence of microbial respiration (Lance and Whisler, 1972).

The physical and chemical adsorption of NH_3 on organic matter could account for the removal of a

significant amount of N from wastewater. This reactions can occur under both aerobic and anaerobic conditions, but primarily above pH 7. The net removal was probably due to a combination of the reactions mentioned above.

Thus from the above discussions it may be concluded that soil III is more efficient in N removal from wastewater and the depth of soil bed required is about 45 cms.

Total Coliforms Removal : Fig. 5.12 shows the variation of total coliforms in influent and effluent from columns with soil I and soil II of different soil depths. The coliforms were never found in the effluents from columns with soil III of any depth. The detailed results are presented in Appendix-Table 5. The total coliforms in the influent ranged from 4.5×10^3/ml to 39.7×10^3/ml with an average of 20.9×10^3/ml. The total coliforms reduced by a minimum of about one order of magnitude with soil I, while the reduction is much higher with soil II, and almost complete reduction occurred with soil III. From the results it can be said that the removal of coliforms from wastewater is highly influenced by the particle size distribution and the sorptive capacity of the soils. Though total coliforms are indicators of the possible presence of pathogenic organisms they are also indigenous to soil and the detection of these organisms is not a positive

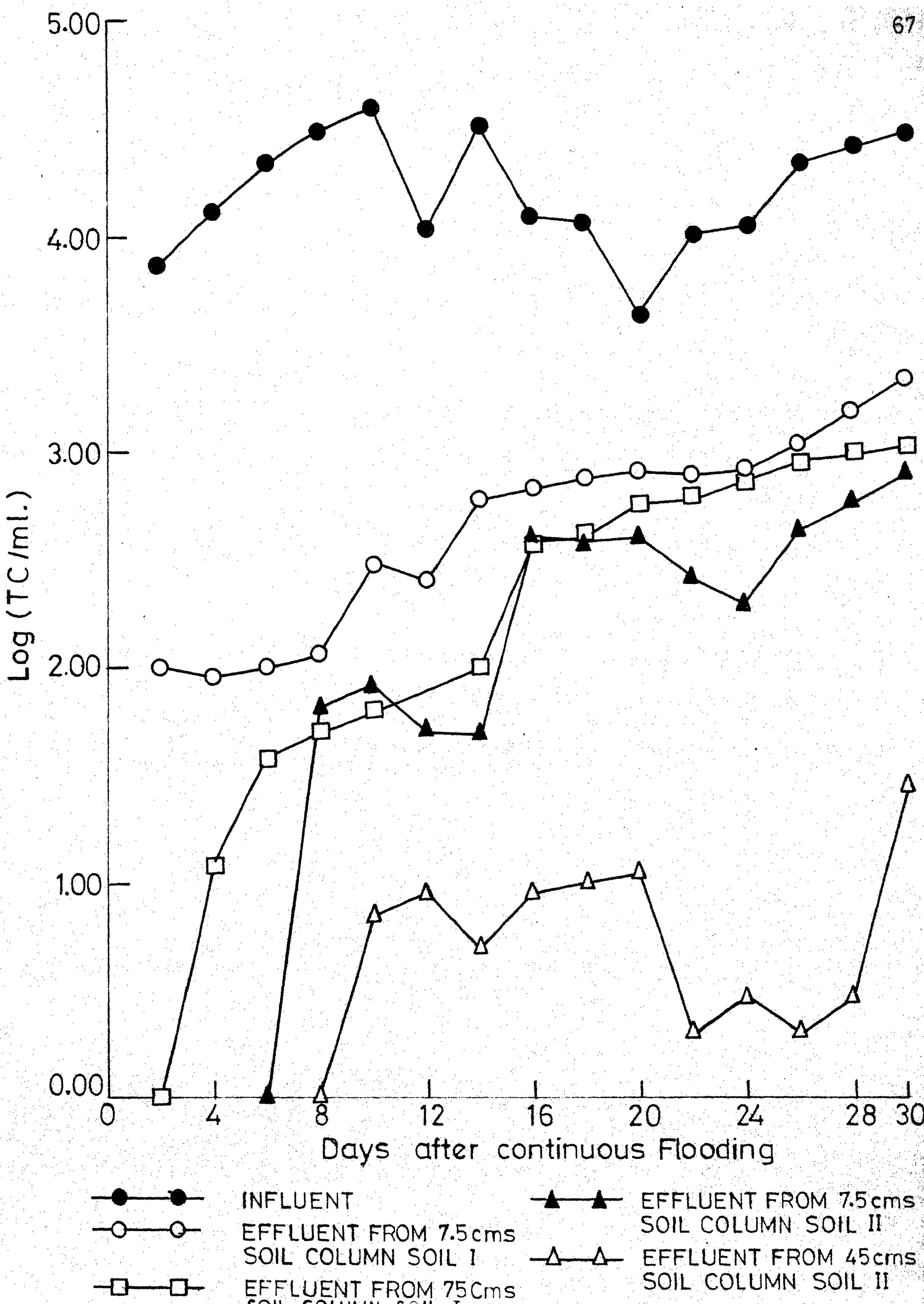

FIG. 5.12 TOTAL COLIFORMS IN INFLUENT AND EFFLUE
FROM SOIL COLUMNS.

evidence of the presence of pathogenic organisms originating from wastewater. However, the absence of coliforms in the effluent can act as an evidence of the absence of pathogenic organisms as coliforms characteristically compete with fecal streptococci, fecal coliforms and pathogenic organisms (Magdoff, et.al., 1974). Waksman (1952) and Hutchinson, et.al. (1943) showed that bacteria of the genus pseudomonas as well as other soil bacteria produce antibiotic and bacteriostatic substances and thus exclude the possibility of the survival of pathogenic organisms in the soil environment if aerobic conditions exists.

5.3 Phase-II Studies:

Phase-II studies were conducted to evaluate the effect of hydraulic loading on the purification of wastewater by soils and the period of continuous application of wastewater till hydraulic failure occurs. Soil III was used in this study as it was found suitable from wastewater acceptance rate and treatment point of view from preliminary and Phase-I Studies. In all three sets of columns with 7.5 cms, 15 cms, 30 cms and 45 cms soil depth were used. Each set of columns was loaded with different hydraulic loadings. The loading rates used were 0.096 cu.m./sq.m./day (2 gpd/sq.ft.) applied twice a day, 0.144 cu.m./sq.m./day

(3 gpd/sq.ft.) applied three times a day, and 0.24 cu.m./sq.m./day (5 gpd/sq.ft.) applied five times a day. Results of this phase of study are presented in Appendix-Table 6-7.

Comparing the results of Phase-I Studies with soil III and Phase-II Studies with respect to purification of wastewater, it can be concluded that rate of hydraulic loading does not play an important role. However, it has a great effect on the service time. The hydraulic failure occurred after 37 days of continuous application of wastewater at a loading rate of 0.24 cu.m./sq.m./day. Table 5.2 shows the percolation rates when hydraulic failure occurred.

TABLE 5.2

Observed Percolation Rates

Hydraulic loading cu.m./sq.m./day	0.24	0.144	0.096
Percolation Rates after 37 days of wastewater application, cms/day	39.0	76.0	88.0

From the percolation rates observations it is clear that the period required to reach hydraulic failure is not only a function of rate of loading, but also depends

on the dry period available before the next wet period. With lower rate of loading the dry period available was more, and hence the higher percolation rate. This leads to the conclusion that wastewater application technique also plays a significant role in the duration of service time for wastewater treatment by soils.

5.4 Phase-III Studies

Phase-III studies were done to evaluate the effect of initial chemical treatment (alum coagulation) on the treatment capacity of the soils and the service time i.e. the time for which a soil system can be used continuously for wastewater application. The soils used were soil I and soil III and the depth of the soil column used was about 45 cms because from the Phase-I and Phase-II studies it was found that almost complete purification of wastewater occurs in top 45 cms of soil depth. The wastewater was applied at the rate of 0.24 cu.m./sq.m./day (5 gpd/sq.ft.) as hydraulic failure occurred with this rate of loading in Phase-II Studies.

The chemical treatment to wastewater removed about 40 to 45 percent C.O.D., 60 to 65 percent phosphates, 20 to 25 percent ammonia nitrogen, 30 to 35 percent total nitrogen and about 40 to 45 percent coliforms. The optimum

dose of alum was 200 mg/lit. at pH of about 7.8. The aim of the initial treatment was to reduce suspended solids and organic loading keeping the same hydraulic loading, so as to achieve an increase in the service time and the treatment capacity.

The results of this phase of study are presented in Appendix--Table 8 and discussed with respect to the treatment achieved as follows:

C.O.D. Removal : C.O.D. in the influent following the coagulation varied from 62.1 mg/lit. to 104 mg/lit, and the C.O.D. removal ranged from 67 to 75 percent with soil I and 91 to 100 percent with soil III. The percentage C.O.D. removal with soil III is increased as compared to that obtained in Phase-II studies at the same rate of hydraulic loading which may be a result of pretreatment. The previous work of Thomas, et.al. (1969) also indicated that pretreatment given to wastewater affects the degree of treatment achieved when the same percolates through soils.

Phosphate Removal: Phosphates in the influent to the soil system following the coagulation treatment varied from 2.7 mg/lit. to 4.3 mg/lit. No measurable concentration of phosphate was observed in the effluent with both types of soils.

Ammonia and Total Nitrogen Removal: Ammonia nitrogen removal was not affected by the pretreatment. However, total nitrogen removal seems to have been improved. The influent ammonia and total nitrogen varied from 11.4 mg/lit. to 17.2 mg/lit., and 12.8 mg/lit. to 19.0 mg/lit. respectively. Ammonia nitrogen removal was about 90 to 95 percent with soil I while complete removal occurred with soil III. The total nitrogen removal ranged from about 74 to 90 percent with soil I while it was about 90 to 95 percent with soil III.

Coliform Removal : There is no appreciable difference in coliforms removal through soils by pretreatment. Though the coliforms removal in alum treatment was about 40 percent, the influent coliform number following the alum treatment to wastewater did not reduce to a great extent and ranged from 4.2×10^3/ml to 11.1×10^3/ml. The minimum coliform removal is about 81 percent with soil I, while coliforms were never traced in effluent from column with soil III.

Service Time : Service time is the most important factor which is affected by the pretreatment given to wastewater. The service time, i.e. the time in days of continuous application of wastewater to the soil till the hydraulic failure occurs, was 37 days with the hydraulic loading of 0.24 cu.m./sq.m./day

with soil III when untreated wastewater was applied to the soil columns. Hydraulic failure did not occur even in 90 days of continuous application of wastewater at the above mentioned hydraulic loading and soil type when the wastewater was given alum treatment before applying to soil columns. The increase in service time thus achieved amounts to about more than three times.

Thus from the preceeding discussion it can be said that alum treatment given to wastewater before applying to soil system enhances the wastewater purification and the service time to a great extent.

6. SUMMARY AND CONCLUSIONS

The results of the present study show that the grain size distribution of the soil plays a dominant role in the effectiveness of the wastewater treatment by soils. Fine silt fraction (-75 μm) has a great capacity to assimilate contaminants from wastewater, but lower initial percolation rate (18.52 cms/day) and **faster** reduction of the same through them limits their use as a wastewater treatment media. Sand on the otherhand, though has a high percolation rate (15.42 x 10^3 cms/day), does not give any guarantee against ground water pollution. From the study it was observed that 60 percent sand (+ 75 μm, effective size = 180 μm, and uniformity coefficient = 2.11) and 40 percent finer fraction (-75 μm, effective size 1 μm, uniformity coefficient 20.0) seems to be the optimum soil system as it does not reduce the percolation rate to limit its use as a wastewater treatment method, at the same time it gives an effluent which is substantially free from physical, chemical and biological contaminants. It was observed that, with the above composition of soils 45 cms of soil depth is sufficient to remove almost all pollutants.

The rate of loading and the application technique has a significant effect on the service time for

which soils can be loaded continuously for wastewater disposal. It was observed that the loading rate should not be more than 0.24 cu.m./sq.m./day (5 gpd/sq.ft.) as it will reduce the service time to a great extent. With a rate of loading of 0.24 cu.m./sq.m./day hydraulic failure occurred after 37 days of continuous flooding period. However with the lower rates of loading viz. 0.096 cu.m./sq.m/day (2 gpd/sq.ft.) and 0.144 cu.m./sq.m./day (3 gpd/sq.ft.) hydraulic failure can be postponed for a significant period as is obvious from the percolation rate observations. It was also observed that the soils can regain the assimilative capacity during the rest period as was shown from the increase in percolation rate after the soil columns were rested for 15 days.

Initial chemical treatment, which included an alum coagulation, at the dose of 200 mg/lit. with a rapid mixing for 1 minute at 100 RPM and a slow mixing for 30 minutes at 20 RPM followed by 30 minutes settling, to the wastewater was very effective in enhancing the treatment capacity of the soils as well as the service time during continuous use. The service time increased to about more than 90 days as against 37 days for untreated wastewater at the loading rate of 0.24 cu.m./sq.m./day (5 gpd/sq.ft.). The increase in service time thus achieved is about three times.

Thus based on the findings of this investigation following conclusions may be drawn:

(1) Particle size distribution plays a dominant role in wastewater treatment and acceptance rate by the soils. Thus it can be a criterian, for the suitability of a particular soil for wastewater treatment. Also the presence of finer fraction (-75 μm) greater than 40 percent affects the suitability adversly.

(2) Forty five cms of soil depth is sufficient to remove almost all pollutants if the soil contains about 60 percent coarse fraction (+ 75 μm) and 40 percent finer fraction (-75 μm).

(3) The degree of treatment achieved is independent of the rate of loading, though the loading rate has a great influence on the service time for which the soils can be used continuously for wastewater application and treatment.

(4) Wastewater application technique viz. the distribution of wastewater to soils and the frequency of flooding is very important in achieving the desired results.

(5) Initial chemical treatment given to wastewater not only increases the service time but also enhances the treatment capacity of the soil system.

7. ENGINEERING SIGNIFICANCE AND SUGGESTIONS FOR FUTURE WORK

7.1 Engineering Significance:

The present study is significant from the point of view of developing a suitable soil system and the hydraulic loading pattern being applied to it for wastewater purification This method can serve as an alternate to tertiary treatment of wastewater and final disposal for large cities where stream flows are restricted, particularly in arid regions. Further in a developing country like India, where most of the rural and urban areas do not have any sophisticated units for wastewater treatment, this method of wastewater purification in conjunction with primary waste treatment processes like sedimentation and alum coagulation may prove to be the only suitable method.

The soil system after accepting the wastewater for several flooding cycles will be enriched with nitrogen from influent wastewater. The soil system used for wastewater treatment may be advantageously used for agriculture during dry cycle as it has necessary carbon to nitrogen (C/N) ratio. If the C/N ratio of the soil is lower than it may be used as compost material for improving the agricultural

value of the land.

Thus, the present work clearly indicates that the wastewater treatment by interaction with soil systems appear to have great potential not only in terms of its simplicity in operation and maintenance but also enhances the soil fertility by nutrient enrichment.

7.2 Suggestions for future work:

Based on the results of this study it is felt that further work should be pursued in the following areas:

1. More studies should be undertaken to develop suitable soil systems by selecting combinations of different locally available soils to make this method of wastewater treatment suitable throughout the country.

2. Field studies should be carried out to supplement the current work and the results should be compared to evaluate some of the non dimentional parameters which may lead to rational design criteria for wastewater treatment by soils.

3. Future laboratory studies in this area should be planned to evaluate the potential of exhausted soils as a soil conditioner for agricultural lands.

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APPENDIX

TABLE 1

Effect of Mixing Silty Soil with Sand on COD Removal Through Soil
Loading Rate = 0.048 cu.m./sq.m./day
(1 gdp/sq.ft.)

Influent COD in mg/lit.	Effluent C.O.D. in mg/lit.														
	7.5 cm soil column			15 cms soil column			30 cms soil column			45 cms soil column			75 cms soil column		
	Soil I	Soil II	Soil III	Soil I	Soil II	Soil III	Soil I	Soil II	Soil III	Soil I	Soil II	Soil III	Soil I	Soil II	Soil III
170.0	120.0	70.0	55.0	40.0	35.0	32.8	38.5	33.5	30.0	35.0	30.0	28.0	30.0	25.0	20.0
100.0	40.0	38.5	30.0	38.0	30.5	28.2	35.5	28.0	26.5	30.0	25.8	16.0	25.0	20.0	10.5
124.8	38.4	35.0	33.0	35.0	32.0	30.0	32.5	30.0	28.0	28.4	24.0	15.0	22.0	15.5	9.6
86.4	40.0	30.0	28.0	35.0	27.0	25.0	33.0	24.5	23.4	29.5	20.5	6.0	24.5	10.0	0.0
163.2	35.0	30.0	29.0	33.0	27.0	25.0	30.5	25.0	21.8	25.5	15.0	6.0	20.0	0.0	0.0
86.4	30.0	28.5	27.0	28.9	25.5	22.0	27.0	22.5	17.5	24.0	12.1	0.0	20.0	0.0	0.0
96.0	38.5	33.0	30.0	33.0	27.0	26.5	30.0	23.0	19.0	26.8	14.0	0.0	24.0	0.0	0.0
165.0	34.0	30.0	26.5	32.0	26.0	22.0	30.0	20.0	12.5	26.0	10.0	0.0	22.0	5.8	0.0
120.0	32.5	30.0	25.8	30.0	25.0	20.5	28.5	18.5	15.0	27.2	9.6	4.5	20.0	8.5	0.0
100.0	30.0	27.0	20.0	29.0	22.8	18.8	27.0	16.0	12.5	25.0	14.0	5.8	20.0	10.0	0.0
100.0	35.5	34.0	24.0	33.0	26.0	20.0	30.5	18.6	16.4	28.0	16.8	7.5	21.5	10.0	0.0
130.0	37.0	36.0	25.0	34.5	27.1	20.0	31.8	19.0	16.4	26.0	16.8	9.6	23.0	10.0	0.0
145.0	40.0	38.0	55.0	35.3	30.5	27.0	32.0	23.5	22.0	30.0	20.9	9.6	25.0	12.8	0.0
100.0	37.7	35.0	32.0	33.0	29.0	26.8	31.0	23.0	21.5	29.5	18.0	10.0	25.0	15.0	5.0
113.0	40.0	37.0	34.0	36.2	31.5	28.0	34.0	28.0	25.5	31.5	23.4	10.0	28.0	15.0	9.6

TABLE 2

Effect of Mixing Silty Soil with Sand on Phosphate Removal Through Soil
Loading Rate = 0.048 cu.m./sq.m./day(1 gpd/sq.ft.)

Influent Phosphate -P in mg/lit.	Effluent Phosphate-P in mg/lit.														
	7.5 cms soil column			15 cms soil column			30 cms soil column			45 cms soil column			75 cms soil column		
	Soil I	Soil II	Soil III	Soil I	Soil II	Soil III	Soil I	Soil II	Soil III	Soil I	Soil II	Soil III	Soil I	Soil II	Soil III
10.80	2.8	0.0	0.0	0.6	0.0	0.0	0.4	0.0	0.0	0.3	0.0	0.0	0.1	0.0	0.0
6.50	1.0	0.0	0.0	0.75	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
9.00	2.05	0.0	0.0	0.60	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0.	0.0	0.0
6.40	2.10	0.2	0.0	0.96	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
6.20	1.60	0.40	0.0	1.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
9.0	2.10	0.80	0.0	1.05	0.0	0.0	0.25	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
8.70	1.50	0.50	0.0	0.75	0.0	0.0	0.10	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
8.4	0.95	0.10	0.0	0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
8.5	1.30	0.70	0.0	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
11.0	1.80	1.00	0.0	1.40	0.0	0.0	0.85	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
6.5	2.26	1.30	0.0.	1.40	0.0	0.0	0.45	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
11.0	1.50	0.80	0.0	1.10	0.0	0.0	0.75	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
10.8	3.0	0.40	0.0	1.50	0.0	0.00	0.85	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
9.0	1.70	1.15	0.0	1.25	0.0	0.0	0.10	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
6.3	2.30	1.30	0.0	1.35	0.0	0.0	0.95	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

TABLE 3

Effect of Mixing Silty Soil with Sand on Ammonia Nitrogen Removal Through Soil
Loading Rate = 0.048 cu.m./sq.m./day(1 gpd/sq.ft.)

No. of days	Influent Ammonia Nitrogen -N in mg/lit.	Effluent Ammonia Nitrogen-N in mg/lit.														
		7.5 cms soil column			15 cms soil column			30 cms soil column			45 cms soil column			75 cms soil column		
		Soil I	Soil II	Soil III	Soil I	Soil II	Soil III	Soil I	Soil II	Soil III	Soil I	Soil II	Soil III	Soil I	Soil II	Soil III
1	14.50	3.6	1.8	1.3	1.5	1.2	0.8	1.3	0.9	0.7	1.1	0.7	0.5	0.4	0.3	0.2
3	14.25	5.8	1.0	0.2	2.2	0.7	0.1	1.2	0.0	0.0	0.7	0.0	0.0	0.0	0.0	0.0
5	21.50	9.9	1.7	1.2	3.0	0.5	0.2	1.8	0.0	0.0	0.8	0.0	0.0	0.0	0.0	0.0
7	15.00	11.2	1.3	0.0	3.2	0.5	0.0	2.0	0.0	0.0	0.6	0.0	0.0	0.0	0.0	0.0
9	13.00	11.2	4.3	0.0	7.2	0.0	0.0	2.2	0.0	0.0	0.7	0.0	0.0	0.0	0.0	0.0
11	21.25	13.2	4.3	1.9	10.1	0.0	0.0	1.3	0.0	0.0	0.5	0.0	0.0	0.0	0.0	0.0
13	17.25	11.4	5.0	0.7	9.5	0.3	0.0	3.5	0.0	0.0	1.6	0.0	0.0	0.0	0.0	0.0
15	13.00	9.2	4.1	0.9	9.2	0.7	0.0	2.9	0.0	0.0	1.9	0.0	0.0	0.0	0.0	0.0
17	15.00	11.9	4.3	1.7	9.9	1.1	0.0	3.0	0.0	0.0	0.7	0.0	0.0	0.0	0.0	0.0
19	20.00	11.2	3.2	2.3	6.1	0.9	0.1	2.0	0.0	0.0	0.4	0.0	0.0	0.0	0.0	0.0
21	19.25	11.2	3.0	1.5	5.0	1.6	0.0	1.7	0.0	0.0	1.2	0.0	0.0	0.0	0.0	0.0
23	18.50	9.4	5.2	1.6	3.2	2.0	0.0	0.9	0.0	0.0	0.25	0.0	0.0	0.0	0.0	0.0
25	13.00	11.2	7.7	1.6	3.8	3.5	0.0	1.5	0.0	0.0	0.7	0.0	0.0	0.0	0.0	0.0
27	16.75	10.7	5.5	2.4	3.2	3.0	0.0	1.3	0.0	0.0	0.4	0.0	0.0	0.0	0.0	0.0
29	13.00	12.2	4.6	3.0	3.2	2.5	0.0	1.5	0.0	0.0	0.3	0.0	0.0	0.0	0.0	0.0

TABLE 4

Effect of Mixing Silty Soil with Sand on Total Nitrogen Removal through Soil

Loading Rate = 0.048 cu.m./sq.m./day (1 gpd/sq.ft.)

Influent Total Nitrogen-N in mg/lit.	Effluent Total Nitrogen-N in mg/lit.														
	7.5 cms soil column			15 cms soil column			30 cms soil column			45 cms soil column			75 cms soil column	
	Soil I	Soil II	Soil III	Soil I	Soil II	Soil III	Soil I	Soil II	Soil III	Soil I	Soil II	Soil III	Soil I	Soil II
16.00	7.00	3.00	1.50	3.50	1.75	1.10	3.25	1.50	0.92	2.15	1.30	1.00	1.75	1.50
15.50	6.50	1.75	1.50	3.00	1.50	1.25	3.00	1.50	1.00	2.60	0.94	0.90	5.25	2.25
25.25	14.25	5.25	4.25	9.25	3.75	2.60	3.00	2.90	2.50	2.50	2.5	2.40	5.00	4.25
13.75	15.25	7.25	3.00	13.25	4.00	3.50	2.75	2.30	2.00	2.10	2.00	1.90	4.25	4.00
30.75	19.50	10.25	3.75	14.25	3.50	3.40	5.75	3.00	2.00	4.25	1.50	1.40	5.00	4.25
28.50	20.0	11.50	5.00	18.00	3.75	2.75	6.50	3.00	2.00	5.00	2.33	2.14	8.00	3.50
20.00	17.40	10.00	3.5	16.00	2.60	2.00	7.50	2.40	1.40	5.60	2.0	1.81	7.00	-
17.00	14.50	8.70	1.56	14.00	1.50	1.30	8.50	2.00	0.80	6.25	1.25	1.15	6.25	2.80
17.75	12.75	7.50	5.38	11.12	4.82	1.75	7.70	1.50	1.44	5.00	0.90	0.82	5.00	1.93
23.00	14.37	5.88	3.00	13.50	5.25	1.88	6.75	1.75	1.00	4.00	1.38	1.22	3.75	3.06
21.50	12.00	6.00	3.00	7.87	4.50	1.81	4.00	2.00	1.50	2.75	1.45	1.34	2.50	2.10
23.00	9.25	5.74	4.00	5.50	5.00	1.81	1.00	1.88	1.75	2.30	1.05	1.00	3.25	1.76
25.75	13.75	9.00	4.00	5.625	6.12	3.14	1.75	2.38	1.40	1.75	1.14	1.10	1.85	1.76
18.75	14.00	6.56	4.00	5.40	5.50	2.56	1.50	2.06	1.00	1.25	0.88	0.80	1.50	1.40
16.50	14.38	6.88	4.60	5.375	4.19	1.56	3.50	1.31	0.75	3.25	0.88	0.78	3.00	2.31

TABLE 5

Effect of Mixing Silty Soil with Sand on Total Coliforms Removal Through Soil
Loading Rate = 0.048 cu.m./sq.m./day (1 gpd/sq.ft.)

No. of days	Influent Total Coliforms in No./ml	Effluent Total Coliform in No./ml														
		7.5 cms soil Column			15 cms soil column			30 cms soil column			45 cms soil column			75 cms soil column		
		Soil I	Soil II	Soil III	Soil I	Soil II	Soil III	Soil I	Soil II	Soil III	Soil I	Soil II	Soil III	Soil I	Soil II	Soil III
2	7×10^3	100	00	00	80	00	00	70	00	00	46	00	00	00	00	00
4	12.5×10^3	92	00	00	40	00	00	30	00	00	20	00	00	12	00	00
6	22.3×10^3	98	00	00	85	00	00	80	00	00	55	00	00	38	00	00
8	30×10^3	120	65	00	100	00	00	90	00	00	69	00	00	50	00	00
10	39.7×10^3	300	82	00	157	10	00	145	09	00	131	07	00	61	00	00
12	10.4×10^3	240	51	00	240	12	00	130	08	00	109	09	00		00	00
14	29.4×10^3	608	50	00	300	21	00	276	36	00	241	05	00	100	00	00
16	12.25×10^3	700	405	00	620	31	00	560	21	00	523	09	00	380	00	00
18	11.6×10^3	760	386	00	710	24	00	685	-	00	670	10	00	410	00	00
20	4.5×10^3	850	328	00	830	25	00	800	16	00	735	11	00	585	00	00
22	10.5×10^3	795	260	00	694	75	00	680	50	00	666	02	00	610	00	00
24	11.4×10^3	942	200	00	900	160	00	850	23	00	820	03	00	766	00	00
26	21.75×10^3	1107	440	00	1070	200	00	1005	10	00	980	02	00	911	00	00
28	26.2×10^3	1556	600	00	1284	180	00	1150	12	00	1000	03	00	970	00	00
30	30.8×10^3	2240	800	00	2000	400	00	1800	88	00	1220	.29	00	1090	00	00

TABLE 6

Effect of Loading Rate on C.O.D. Removal Through Soil
Soil Type : Soil III

No. of days	Influent C.O.D. in mg/lit	Effluent C.O.D. in mg/lit.														
		7.5 cms soil column			15 cms soil column			30 cms soil column			45 cms soil column			75 cms soil column		
		Loading Rate in cu.m./sq.m./day														
		0.096	0.144	0.24	0.096	0.144	0.24	0.096	0.144	0.24	0.096	0.144	0.24	0.096	0.144	0.24
1	130.0	38.4	40.0	41.6	25.6	27.8	28.2	20.4	22.0	23.4	11.7	13.2	14.4	10.5	11.6	12.2
3	190.0	40.3	41.6	42.0	26.8	28.0	28.6	20.8	22.2	23.5	12.9	13.4	14.6	10.6	11.8	12.2
5	140.0	37.0	38.1	38.6	23.8	24.0	25.1	18.4	19.6	20.0	10.3	11.8	12.0	8.6	9.2	10.0
7	90.0	26.5	28.2	29.0	20.1	21.2	22.4	16.1	16.4	16.8	8.4	9.6	9.8	6.4	6.6	7.2
9	90.0	24.2	26.6	27.8	19.8	20.5	21.4	14.0	15.0	15.8	7.8	8.2	8.6	5.8	6.0	6.4
11	100.0	22.1	24.0	26.6	16.4	18.8	19.0	12.3	13.8	14.0	6.4	7.8	8.0	3.2	3.6	3.7
13	110.0	22.6	24.1	26.8	16.6	19.0	19.1	12.4	13.8	14.1	6.4	7.6	7.9	3.0	3.2	3.2
15	140.0	27.4	29.0	30.1	20.1	21.0	21.0	14.6	15.2	15.4	6.8	7.8	8.0	3.4	3.6	3.6
17	120.0	25.3	26.8	27.4	19.0	20.9	21.4	14.4	14.8	15.0	6.9	8.0	8.0	3.6	3.6	3.8
19	145.0	28.0	29.3	30.1	22.2	23.4	23.8	15.8	16.4	16.6	7.1	7.9	8.2	3.7	3.8	3.8
21	124.8	22.6	24.5	26.4	18.6	19.2	20.1	14.6	15.0	15.5	6.8	7.5	7.8	3.8	3.8	4.0
23	120.0	22.0	24.0	26.0	18.0	19.0	20.1	14.2	15.6	15.0	6.6	7.2	7.6	3.2	3.4	3.6
25	120.0	22.4	25.8	27.1	19.2	20.0	20.6	14.4	15.1	15.2	6.4	6.8	7.0	2.2	2.6	2.9
27	105.6	20.3	22.6	24.0	17.9	18.4	20.2	13.8	14.6	15.0	5.8	6.0	6.6	0.0	0.8	1.2
29	144.0	28.6	30.2	31.1	21.4	23.0	24.1	15.2	15.4	15.8	7.2	8.8	9.0	2.8	3.0	3.0
31	150.0	28.8	31.0	31.0	22.0	23.0	24.0	15.8	16.0	16.4	7.6	8.8	9.1	2.9	3.4	3.6
33	130.0	30.2	32.0	32.5	22.8	24.2	24.8	16.0	16.8	17.2	7.8	9.0	9.5	3.2	3.8	4.0
35	120.0	30.2	32.3	32.6	22.8	24.4	25.0	16.8	17.4	17.8	8.0	9.2	9.6	3.6	3.8	4.1
37	120.0	31.6	33.4	33.9	23.0	25.0	25.4	17.2	18.0	19.0	8.1	9.4	9.8	3.8	4.1	4.6

TABLE 7

Effect of Loading Rate on Total Nitrogen Removal Through Soil Soil III

No. of days	Influent Total Nitrogen -N in mg/lit.	Effluent Total Nitrogen-N in mg/lit.														
		7.5 cms soil column			15 cms soil column			30 cms soil column			45 cms soil column			75 cms soil column		
		Loading Rate in cu.m./sq.m./day														
		0.096	0.144	0.24	0.096	0.144	0.24	0.096	0.144	0.24	0.096	0.144	0.24	0.096	0.144	0.24
1	24.50	3.0	3.5	4.0	1.6	1.8	2.0	1.1	1.2	1.3	0.9	1.0	1.1	1.0	1.0	1.1
3	26.30	3.2	3.3	4.2	1.7	1.8	1.9	1.2	1.2	1.3	0.8	0.9	0.9	0.9	1.0	1.0
5	23.20	2.8	3.2	3.6	1.2	1.4	1.4	0.8	0.9	1.0	0.3	0.4	0.4	0.4	0.5	0.6
7	17.10	2.2	2.8	3.2	1.0	1.2	1.3	0.7	0.8	0.9	0.5	0.5	0.7	0.7	0.5	0.8
9	17.15	2.3	2.9	3.4	1.1	1.3	1.3	0.7	0.7	0.8	0.4	0.4	0.5	0.5	0.5	0.6
11	19.30	2.9	3.4	3.8	1.2	1.3	1.4	0.8	0.9	1.0	0.7	0.8	0.9	0.8	0.8	0.9
13	21.40	3.0	3.5	3.9	1.2	1.4	1.5	0.9	0.9	1.0	0.4	0.5	0.6	0.4	0.6	0.7
15	23.85	3.1	3.3	3.8	1.4	1.5	1.7	0.9	1.0	1.1	0.6	0.6	0.7	0.7	0.6	0.8
17	25.45	3.2	3.6	4.0	1.4	1.4	1.4	1.0	1.1	1.1	0.5	0.5	0.7	0.6	0.6	0.7
19	30.75	3.2	3.8	4.2	1.5	1.6	1.7	1.0	1.0	1.2	0.4	0.6	0.6	0.4	0.8	0.8
21	26.10	2.8	3.2	4.0	1.2	1.3	1.5	1.0	1.1	1.2	0.5	0.7	0.7	0.5	0.7	0.7
23	25.30	2.6	2.9	3.3	1.1	1.4	1.6	0.9	1.0	1.1	0.6	0.6	0.8	0.6	0.7	0.9
25.	25.30	2.4	2.9	3.2	1.0	1.2	1.5	0.5	0.6	0.6	0.3	0.5	0.6	0.4	0.6	0.7
27	18.15	2.2	2.6	3.0	0.9	1.1	1.2	0.8	0.8	0.9	0.4	0.4	0.5	0.5	0.6	0.7
29	18.30	2.3	2.9	3.5	1.2	1.2	1.3	0.7	0.9	1.0	0.3	0.5	0.6	0.4	0.5	0.6
31	31.05	3.4	3.7	4.0	1.4	1.5	1.5	0.9	0.9	1.1	0.4	0.6	0.7	0.4	0.8	0.9
33	24.60	2.4	2.8	3.4	1.2	1.3	1.5	1.0	1.1	1.2	0.7	0.7	0.8	0.8	0.9	0.9
35	26.00	2.6	3.0	3.6	1.3	1.5	1.7	1.0	1.1	1.1	0.8	0.9	1.0	0.8	0.9	1.1
37	25.35	2.5	2.9	3.6	1.4	1.5	1.9	1.1	1.2	1.2	0.8	1.0	1.0	0.9	1.1	1.1

TABLE 8

Effect of Initial Treatment on Effluent Quality from Soils
Loading Rate = 0.24 cu.m./sq.m./day (5 gpd/sq.ft)
Depth of Soil Columns = 45.0 cms

No. of days	C.O.D. in mg/lit.			Phosphate-P in mg/lit.			Ammonia Nitrogen-N in mg/lit			Total Nitrogen-N in mg/lit			Total Califorms in No./ml		
	Influent	Effluent		Influent	Effluent		Influent	Effluent		Influent	Effluent		Influent	Effluent	
		Soil I	Soil III		Soil I	Soil III		Soil I	Soil III		Soil I	Soil III	$x10^3$	Soil I	Soil III
1	102.8	30.1	16.4	4.1	0.2	0.0	17.0	1.6	0.0	18.20	2.6	0.9	11.1	66	00
5	72.0	21.4	12.3	3.2	0.0	0.0	11.9	0.9	0.0	12.1	1.0	0.1	7.0	43	00
10	80.4	23.8	10.0	3.6	0.0	0.0	12.6	1.9	0.0	14.5	2.5	0.5	8.3	78	00
15	64.0	20.0	6.8	2.9	0.0	0.0	11.6	1.6	0.0	13.3	2.1	0.4	4.2	60	00
20	73.1	26.1	9.2	3.5	0.0	0.0	12.2	2.0	0.0	14.3	3.0	0.7	6.9	98	00
25	82.0	27.5	8.4	3.8	0.0	0.0	13.1	2.1	0.0	15.6	3.2	0.9	7.8	131	00
30	96.0	25.4	7.2	4.2	0.0	0.0	15.9	2.3	0.0	17.3	8.4	1.0	8.1	180	00
35	100.0	23.0	6.0	4.3	0.0	0.0	16.2	2.2	0.0	18.0	3.5	1.1	9.2	262	00
40	84.5	23.2	0.0	3.7	0.0	0.0	13.8	1.8	0.0	15.1	2.8	0.8	8.4	240	00
45	72.0	20.2	0.0	3.0	0.0	0.0	12.9	1.5	0.0	14.3	2.4	0.7	6.2	280	00
50	76.4	24.6	0.0	3.1	0.0	0.0	13.1	1.3	0.0	15.3	2.8	0.9	6.8	298	00
55	80.0	24.0	4.3	3.4	0.0	0.0	14.3	1.6	0.0	16.6	2.7	1.0	7.3	364	00
60	88.2	22.8	6.8	3.7	0.0	0.0	15.2	1.8	0.0	17.1	2.7	0.6	7.7	391	00
65	90.6	26.0	7.1	4.0	0.0	0.0	15.2	2.0	0.0	17.4	3.9	1.2	8.5	660	00
70	104.5	28.8	8.9	4.1	0.0	0.0	17.2	2.4	0.0	19.0	3.5	1.0	9.6	332	00
75	80.8	26.7	9.2	3.3	0.0	0.0	13.0	1.8	0.0	15.1	3.8	1.5	9.9	1008	00
80	62.1	20.8	7.8	2.7	0.0	0.0	11.4	1.3	0.0	12.8	2.5	1.0	5.4	912	00
85	74.3	24.1	7.8	3.1	0.0	0.0	12.3	1.6	0.0	14.6	3.1	1.1	6.4	1180	00
90	79.7	23.6	8.4	3.2	0.0	0.0	12.5	1.7	0.0	14.8	2.9	1.2	6.75	1268	00